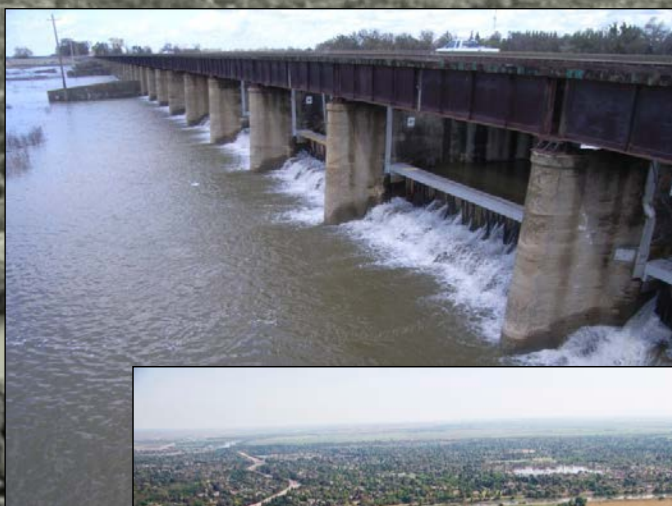
American River Watershed

Common Features
General Reevaluation Report



Attachment B
Hydraulic Report

December 2015

SAFCA
Sacramento Area Flood Control Agency

CENTRAL VALLEY FLOOD PROTECTION BOARD
PUBLIC SAFETY WITH FLOOD PROTECTION
STATE OF CALIFORNIA

US Army Corps of Engineers®
Sacramento District

Cover Photos courtesy of the Sacramento District:
Sacramento Weir during operation
Sacramento River facing south near the Pocket and Little Pocket neighborhoods
High flows on the American River at the Highway 160 overcrossing
Folsom Dam releasing high flows

AMERICAN RIVER, CALIFORNIA
COMMON FEATURES PROJECT
GENERAL REEVALUATION REPORT

Attachment B
Hydraulic Report

U.S. Army Corps of Engineers
Sacramento District

December 2015

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AMERICAN RIVER, CALIFORNIA
COMMON FEATURES PROJECT
GENERAL REEVALUATION REPORT

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1 STUDY DESCRIPTION

1.1 Introduction

This Hydraulic Report summarizes a collection of technical memorandums documenting the hydraulic analysis performed to support the ARCF GRR and has been prepared to meet the intention of the new USACE SMART Planning process – Specific, Measurable, Attainable, Risk-informed and Timely. A complete list of the memorandums cited in this document follows the Table of Contents and are also located in the References section. To support streamlined documentation as part of SMART Planning, the memorandums are referenced but not included with this report. They can be provided on request.

Several significant factors justify a reevaluation of the American River Common Features Project at this time:

1. Since the last authorization of the American River Common Features Project, the scope and cost of levee improvements for the Natomas Basin have increased.
2. New hydraulic modeling and geotechnical studies suggest potential issues with the Sacramento River east levee downstream of the American River. Specifically, the levees have shown evidence of through-seepage and underseepage that could lead to a failure. Such a failure could cause major flooding in the city of Sacramento.
3. There are also additional erosion issues on the American River that will need to be addressed to ensure that the American River can pass 160,000 cubic feet per second (cfs) with some degree of certainty.

Based on these factors, the city of Sacramento may continue to have a high risk of flooding, even with the completion of all authorized improvements in the Natomas Basin, along the Lower American River, and at Folsom Dam.

Previous study efforts of the Natomas Basin under the Natomas GRR were folded into a more broadly scoped American River Common Features General Reevaluation Report. That report considered all the aforementioned issues from a system approach in order to reduce the flood risk in the entire city of Sacramento.

1.2 Location

The project area reflects the area for which alternatives were formulated to meet the planning objectives. The study area is a broader area where the benefits (or impacts) of the alternatives was evaluated. The project area is divided into three basins – Natomas, American River North, and American River South – and has an upstream boundary at Verona and a downstream boundary at Freeport on the Sacramento River (see Plate 4 for the location of these basins). It also includes the leveed portions of the American River, the Natomas Cross Canal, the Natomas East Main Drain Canal (NEMDC), the Pleasant Grove Creek Canal, Magpie Creek, and the leveed portions of Dry and Arcade creeks. The study area for the ARCF GRR includes the above project area and extends beyond it both upstream and downstream. See Plates 1 and 2 for a watershed and a general topographic map, respectively.

Flood control channels and other features in the Sacramento area are part of a much larger flood control system known as the Sacramento River Flood Control Project (SRFCP). The SRFCP in the

Sacramento Valley consists of a series of levees and bypasses, placed to protect urban and agricultural areas and take advantage of several natural overflow basins. See Plate 3 for a graphic depiction of the system layout. The SRFCP system includes levees along the Sacramento River south of Ord Ferry; levees along the lower portion of the Feather, Bear, and Yuba Rivers; and levees along the American River. The system includes the Sutter, and Yolo bypass channels. These bypass channels run parallel to the Sacramento River and receive excess flows from the Sacramento, Feather, and American rivers via overflow channels and constructed weirs. During floods, the flood control system is one continuous waterway.

1.3 Topographic Data

Existing topography and bathymetry were used for most of the study's hydraulic modeling efforts. There were several areas with updates, including the Natomas east side tributaries area for the HEC-RAS model where new surveyed cross sections were developed.

The topography for the HEC-RAS model was previously collected for the Sacramento River Bank Protection Project and the Sacramento San Joaquin Comprehensive Study (Comp Study) UNET model. More detailed descriptions of the hydrographic and topographic surveys completed are in documentation provided by Ayres Associates in support of the Comprehensive Study (References 31, 32).

The geospatial survey data used in the development of the FLO-2D models were obtained from both Sacramento County and the United States Geological Survey (USGS). The Sacramento County information included LiDAR data for the urban area of the county and is dated 2004. The USGS information included publicly available 30-meter USGS Digital Elevation Models (DEMs) which were obtained from http://www.GISdatadepot.com.

All topographic data references the North American Vertical Datum of 1988 (NAVD88) and the North American Datum of 1983 (NAD83), projected in California State Plane Zone 2. The units are in feet. Several of the topographic datasets were created in different vertical datums and significant effort has been made to convert the topographic datasets and hydraulic models into the current standard vertical datum, NAVD88. See both the Technical Memorandum (USACE May2013c) on model datum conversion and the reference on the Comprehensive Study topography conversion (HJW Geospatial, 2010).

1.4 Study Approach

The three basins that are the focus of this GRR – American River North, American River South and Natomas (described in more detail in Chapter 3) are susceptible to flooding from both the American River and Sacramento River. Within the study area, the American and Sacramento rivers were divided into more than 25 river reaches according to the geotechnical similarity of their levees. The number was reduced to five representative reaches that would adequately describe the flood risk within the study area during the plan formulation process.

HEC-RAS (1-dimensional channel model) and FLO-2D (2-dimensional gridded model) hydraulic models were used to produce necessary outputs for the economic evaluation of the future without-project conditions and alternatives. The ARCF GRR used the same basic models that were developed and refined for the existing conditions (F3, March 2009) analyses and the Natomas Post Authorization Change Document (NPAC, 2010). HEC-RAS was used to model the main flood control channels of the system to determine the water surface profiles assuming no levee failure. The model was also used to simulate levee failure scenarios and simulate flood hydrographs into the floodplain areas. This HEC-RAS model includes the major river reaches within the lower portion of the Sacramento River Watershed. This was done to capture upstream and downstream influences to the project area as well as to eventually determine the potential project impacts to areas outside the project area.

Flood hydrographs generated in HEC-RAS from a levee break were input into FLO-2D for delineation of the floodplain in each basin. In order to generate flood damages for economic evaluations, floodplains were delineated for the 50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5% (1/200-Yr) and 0.2% (1/500) annual chance exceedance events. The analysis was limited to flooding within the basin from levee breaches and does not include localized flooding from rainfall-runoff and smaller streams and drainages.

Floodplain delineations presented in this study are based on a single levee break within a levee reach. The levee break location was determined by the most significant geotechnical concerns along that reach and by any overriding hydraulic concerns, such as low levee elevations or locations where a large amount of water could travel through the levee break and out into the floodplain. The resultant flood depths from FLO-2D and the stage-discharge-frequency curves derived from HEC-RAS outputs were used to perform the risk analysis for the without-project condition and the alternatives.

This report presents a very specific and detailed analysis of the with- and without-project conditions for the general Sacramento metropolitan area. Based on an evaluation of study risks, some analyses typically found in a hydraulic appendix have been reduced to a sensitivity analysis, have not been done, or have been postponed to a later date and will likely be completed during design. These efforts are summarized below:

Efforts analyzed using sensitivity:

- Climate change
- Sea level rise
- Interior flooding

Efforts not expected to be completed at this time or in design:

- FEMA accreditation/certification
- Safe overtopping locations and evacuation plans
- Boat wave erosion

Efforts recommended for design or during refinement of selected plan:

- Sedimentation engineering, fluvial geomorphology
- Channel stability, channel stabilization, bridge scour
- Bank projection, vegetation analysis (tree scour)
- Operation and maintenance

The key assumptions for each analysis are listed in Table 1-1.

Table 1-1. ARCF Hydraulic Analyses and Key Assumptions	
ARCF Hydraulic Deliverables	Key Assumptions
Future without-project condition analysis (HEC-RAS, Flo-2D)	The project area is adequately represented by index points at 5 key locations, reduced from over 25.
Evaluation of final alternatives for evaluation (HEC-RAS)	For alternative analysis, large cost measures screened out qualitatively. Many features reduced and combined into final array of alternatives.
With-project floodplain analysis (Flo-2D)	Used without-project floodplains and adjusted frequency of floodplain based on peak stage and volume.
Potential Hydraulic impacts (HEC-RAS)	The baseline for potential hydraulic impacts at Folsom is the future without project condition with the Folsom features(JFP Spillway, Dam Raise) in place.
Residual risk (HEC-RAS, Flo-2D)	Overtopping of American River upstream of leveed reach and Sankey Gap will not be modified by a future project.
Interior drainage	Existing FEMA interior floodplains used in place of full interior drainage analysis.
Systems risk and uncertainty	HEC methodology used based on Reference 5.
Climate change	Sutter methodology used, sensitivity analysis only.
Sea level rise	Used Information from recent study in the Delta and existing sensitivity analysis.
Coincident flow frequency	Based on direction from Hydrology Section Chief, using the n-year event for coincident flows on the Eastside Tributaries and the American River until design, then refinement likely needed.
Superiority	No analysis was performed. Instead, ETL 1110-2-299 was used with bypasses serving as the overtopping locations along with using congressional legislation assumptions specifically for the American River.
Erosion (including riverine/bank, wind-wave, and channel stability)	Limited analysis conducted, coordinating with ongoing design efforts that are not yet complete. Erosion repair for the American River is identical to all alternatives.
Vegetation variance	Vegetation Variance Deferred to PED, Hydraulic efforts will be part of erosion scoping, likely a HEC-18 analysis for tree scour.

1.5 Basis of Design

The following is a partial list of USACE guidance used in the hydraulic analysis:

ER 1110-2-1150	Engineering and Design for Civil Works Projects
EC 1110-2-281	Requirements of River Hydraulics Studies
ER 1110-2-8153	Sedimentation Investigations
ER 1110-2-1405	Hydraulic Design for Local Flood Protection Projects
EC 1165-2-201	Ecosystem Restoration in the Civil Works Program
EM 1110-2-1416	River Hydraulics
EM 1110-2-1619	Risk-Based Analysis for Flood Damage Reduction Studies
EM 1110-2-4000	Sediment Investigations of Rivers and Reservoirs
EM 1110-2-1205	Environmental Engineering for Local Flood Control Channels
EM 1110-2-1601	Hydraulic Design of Flood Control Channels
ERDC/CHL TR-01-28	Hydraulic Design of Stream Restoration Projects
ETL 1110-2-299	Design of Overtopping of Levee
EC 1110-2-6067	USACE Levee Certification Guidance

2 PROJECT DESCRIPTION

2.1 Project Area Limits

The project limits for the floodplain north of the American River cover approximately 124 square miles of Sacramento County (see Plate 5). The American River North basin includes the area north of the American River and east of the Natomas East Main Drain Canal (NEMDC). It is separated from the Natomas Basin by the NEMDC. The American River North Basin is bounded on two sides by levees and high ground on the remainder as follows:

- Southern boundary: American River levees from Hazel Avenue to the NEMDC
- Western boundary: NEMDC levees
- Northern boundary: High ground and Elverta Road
- Eastern boundary: High ground

The American River South basin includes the area south of the American River and east of the Sacramento River (see Plate 6). For this effort, it does not include the Morrison Creek Stream Group. The study limits for the floodplain south of the American River cover approximately 254 square miles of Sacramento County and are defined as follows:

- Southern boundary: Morrison Creek Stream Group levees
- Western boundary: Sacramento River levees
- Northern boundary: American River levees from Hazel Avenue to confluence with Sacramento River
- Eastern boundary: High ground

The Natomas Basin is almost completely enclosed by levees and has significant interior drainage works (see Plate 7). The Natomas basin includes the reach of the Sacramento River from the Natomas Cross

Canal to the American River, the Pleasant Grove Creek Canal (PGCC), and the NEMDC. The Natomas basin is bounded as follows:

- Southern boundary: American River levees from the NEMDC to the confluence of the American and Sacramento Rivers
- Western boundary: Sacramento River levees from the Natomas Cross Canal to the confluence of the American and Sacramento Rivers
- Northern boundary: Cross Canal levees
- Eastern boundary: The NEMDC levees to the southern two-thirds of the eastern boundary and levees for a drainage canal connecting to the Cross Canal for the northern one-third of the eastern boundary

There is one location that is not leveed in the Natomas Basin, where the NEMDC and the drainage canal on the eastern boundary meet. This opening is less than a quarter mile in length near Sankey Road, and is commonly referred to as the Sankey Gap.

2.2 Future Without-Project Condition

The Sacramento River system configuration as it generally exists now (between years 2006 and 2014) was used for the future without-project condition with the exception of changes on the American River.

The ARCF GRR study assumes that the work identified in the Natomas PACR Chief's Report has been completed.

This study also assumes that all previously authorized constructed and unconstructed work on the American River, the new spillway being constructed at Folsom Dam, and the future planned raise of Folsom Dam. The Folsom Dam and Spillway were assumed to be operated as described in Appendix B2: American River Hydrology and Folsom Dam Reservoir Operations of the Hydrology Appendix.

As part of the March 2009 Existing Conditions Conference (F3), multiple scenarios were proposed and analyzed for the without-project and future without-project conditions for the American River. Much of the Sacramento River system was expected to be the same under the future without-project condition with the exception of the following:

- Changing operations at Folsom Dam because of the Joint Federal Project Spillway (JFP),
- Levee repairs as described in the "Natomas Post Authorization Change Report"
- Levee repairs as described in the "Authorized American River WRDA 96/99 Sites"

The Project Delivery Team (PDT) decided to analyze conditions needed to justify only the current work proposed by the ARCF GRR document. This decision considered the significant effort already expended and additional effort still needed to answer the question of incrementally justifying projects on the American River. Based on this information as well as profile comparisons, it was determined that it is not necessary to consider the multiple without-project conditions as previously studied.

For the ARCF GRR document, only a single without-project condition was analyzed. This condition was known as the NA3 condition in the CF GRR F3 documentation. Because previous nomenclature used was confusing, a new naming system was developed. The NA3 condition is now known as the Authorized Common Features + Joint Federal Plan + Dam Mini-Raise (ACF + JFP + Dam Mini-Raise). This plan includes all previously authorized constructed and unconstructed work on the American River, the new spillway being constructed at Folsom Dam, and the future planned raise of Folsom Dam.

All this is considered to be part of the without-project condition. Any work beyond the without-project condition, proposed under the ARCF, is considered part of the with-project condition.

3 CHANNEL HYDRAULICS

3.1 Background

This chapter documents the HEC-RAS model development and calibration for the Sacramento River Basin river system in support of the ARCF GRR. HEC-RAS is a 1-D hydraulic model that can be run in steady or unsteady mode. The model for the Sacramento River Basin was generated from a combination of several previous modeling efforts, many of which modeled a portion of the Sacramento Basin. Previous modeling was supplemented with new modeling for some reaches.

A basin-wide UNET model was previously developed for the Sacramento Basin as part of the Sacramento and San Joaquin River Basins Comprehensive Study (Comp Study. As part of the F3, the entire model was converted from UNET to HEC-RAS, with the exception of the Butte Basin and the Sacramento River north of Colusa. All modeling is currently being done using HEC-RAS. Handoffs from the UNET model in the form of flow hydrographs were used as upstream boundary conditions for the HEC-RAS model. Details regarding development of the HEC-RAS model are contained in the Sacramento Basin HEC-RAS Phase I Development Technical Memorandum (USACE May 2013i).

Modeling of the study area was done in different phases in order to avoid delays to the major milestones of the ARCF GRR schedule. Phase 1(USACE May 2013i) of the model development was completed previously and supported the Natomas Post Authorization Change Document (Natomas PAC) in 2010 (the Natomas PAC is a portion of the overall ARCF GRR study). Phase 1 documents the generation of the main geometry files with pertinent features, including representation of major flood control levees in the system. During this phase of model development, the model was calibrated to the 1997 flood event. The model developed under Phase 1 was used to run *n*-year synthetic events, [50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5% (1/200-Yr) and 0.2% (1/500)] for without-project conditions to determine economic damages and to screen alternatives for the Natomas PAC study. This model was based on the NGVD1929 vertical datum.

For Phase 2 of model development, the model was converted to the NAVD1988 vertical datum (USACE, May 2013c). Additional reaches were added to the model, in particular the Natomas east side tributaries (WEST July 2010). Though the model does cover a large portion of the lower Sacramento watershed, its main purpose is not to provide detailed hydraulics for all reaches in the system, but rather to support the ARCF GRR, which is for flood damage reduction efforts in and around Sacramento. Other Corps studies within the Sacramento Basin system, in particular the Sutter County Feasibility Study and the West Sacramento GRR studies, also use the same “base” Phase 2 model, but include refinements pertinent to their particular study reaches. More information on Phase 2 development can be found in the Draft Sacramento Basin HEC-RAS Phase II Development Technical Memorandum (USACE, May2013j).

3.2 Hydrology

Inflow hydrographs to the hydraulic models presented in this report are described in the hydrology report. Hydraulic model simulations were performed for flood frequencies ranging from 50% (1/2) through the 1.2% (1/500) ACE events. The hydrology report includes minor updates were made to the hydrology used in the Natomas Post Authorization Change Report. This includes greater detail and refinement of the tributary streams on the east side of the Natomas Basin and an update on timing of the American River outflows. For a revised map showing locations of boundary conditions, see Plate 57.

3.3 Model Calibration

The model was calibrated to flood events that occurred in 1997 and 2006. The Calibration Technical Memorandum (USACE, May 2013a) includes additional information on the calibration efforts. The 1986, 1997, and 2006 flood events were considered for model validation. The 1986 flood could not be used for validation, however, because it lacked a complete set of data. The 1997 event was selected for calibration because a significant amount of calibration data was collected for the 1997 event. However, this event was complicated by the challenges of accurately representing breach flow through two levee failures. The 2006 event was initially selected for model validation for two reasons: (1) there were no levee failures, even though it produced high stages within the Sacramento Flood Control System, and (2) results of the 2006 event, when compared to high-water mark data and gage data gathered at that time, could be used to test the results of the 1997 calibration. The 2006 was used first to validate the hydraulic model results and then it was also used as a second calibration because there were refinements mostly in terms of weir coefficients. This second calibration effort removes the independence of the model validation and there is not an additional flood event with enough hydrologic information to continue the model validation. However, the 2006 event has been reasonably reproduced and demonstrates the model's ability to reproduce results from multiple events.

Insomuch that calibration was done to both the 1997 and 2006 flood events, two separate model geometries had to be created to account for geometric changes that occurred between 1997 and 2006 that could impact the hydraulics. The first geometry represents the state of the system leading up to the 1997 flood event. The second geometry represents the state of the system leading up to the 2006 flood event. The 2006 geometry is different because it includes the following physical features that were constructed after the 1997 flood event:

1) *Pump Station at the Natomas East Main Drain Canal (NEMDC) / Dry Creek Confluence*
2) *Setback levee at Shanghai Bend on the Feather River*
3) *Setback levee on the Bear River as it meets the Feather River*

Model result hydrographs were compared to gage records and peak stage data, where available, for the 1997 and 2006 flood events. The HEC-RAS model parameters for Manning's *n*, weir coefficients, and levee breaches were then adjusted as needed in an iterative procedure to modify the model results to more closely match the calibration data. The final modeled water surface profiles matched highwater marks, hydrograph peak stages and flows, and hydrograph shapes at numerous gages throughout the system reasonably well.

3.4 Water Surface Profiles

The HEC-RAS model was used to develop water surface profiles for all reaches surrounding the three basins. A suite of seven *n*-year frequency profiles [50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5% (1/200-Yr) and 0.2% (1/500)] is shown in Plates 12–24 for the future without-project condition (FWOP). The FWOP will serve as the baseline for alternative comparison. This suite of model runs included raising the levees along the project reaches high enough to contain all of the flow up to and including the 0.2% (1/500) ACE event through that reach. This approach supported an economic analysis of levee raises at multiple heights above the existing top of levee. The baseline to determine if a levee needs to be raised was set at the median 0.5% (1/200) Annual Chance Exceedance (ACE) plus 3 feet. This assumption is based on both the local sponsor's Urban Levee Design Criteria (DWR 2012) and the intent of the Folsom JFP to control releases up to 160,000 CFS which is currently estimated to be a 0.5% (1/200) ACE event.

This top of levee design of 3 feet above the median 0.5% (1/200) ACE was used on all reaches except the American River where there was already a design water surface profile from the WRDA 1996/1999 Design efforts. The American River top of levee was set at 3 feet above the design flow of 160,000 cfs (currently a median 0.5% (1/200) ACE) at a single index point but this would need to be evaluated in PED for the entire reach for levees on both sides.

There are two unique features on the water surface profiles on Plates 12-24. First, on the NEMDC right bank levee (Plate 19), there is a pump station at RM 6.3 that also acts as a barrier to rising American River backwater flowing up the channel. This is shown by a lower water surface profile upstream of the NEMDC Pump station than on the downstream side. Secondly, during large flood events, water from the American River flows upstream on the Sacramento River to the Sacramento Weir, where it discharges into the Sacramento Bypass (which connects to the Yolo Bypass). This creates a flat or increasing water surface profile downstream of the Sacramento Weir, which can be seen in the profile plates noted above.

3.5 Levee Breach Assumptions

Levee breach model results are needed for input into the 2D floodplain routing model (FLO-2D) to delineate the corresponding floodplains. Several key levee breach assumptions are listed below:

- A levee breach width of 500 feet was used consistently in the models that support the ARCF GRR. Historical precedent shows that 1,000 feet (which the Corps has used on other studies in the Sacramento Basin) is an achievable breach width, but it is on the high end of all known widths. The 500-foot width was chosen as a more reasonable or average value.

- For each model run with a levee break, the trigger elevation for a levee break was set to 0.5 feet below the max water surface of the simulated event at the failure location.

- If the maximum water surface did not reach the toe of levee, it was assumed that the levee did not fail and a breach simulation was not performed.

- The time for the breach to develop was set at 1 hour.

Several of these assumptions were evaluated with a sensitivity analysis and confirmed to not significantly impact the hydraulic results. The sensitivity analysis is discussed further in section 5.2 and the Levee Breach Sensitivity Technical Memorandum (USACE, May 2013h).

4 ALTERNATIVE DEVELOPMENT

4.1 Evaluation of Measures

A wide range of features were evaluated to reduce flood risk in the project area. There are two main strategies to reduce this risk:

- Reduce the consequences of flooding by moving communities to higher ground out of the floodplain, flood proofing, land use changes, and/or other non-structural alternatives.

- Reduce the probability of inundation of structures. This is generally done in one of two ways:
  - Reduce the amount of flood water getting to and through the project area
  - Fortify and improve the current flood defense system

Reducing the consequences of flooding is addressed in the main feasibility report and the economic appendix. Reducing the probability of inundation is addressed starting here in Chapter 4, with additional information found in Chapters 5-7. Measures to reduce the probability of inundation by strengthening or improving the existing flood risk management system are described below, with additional information found in the engineering appendix and its geotechnical attachment.

From a hydraulic perspective, measures to reduce the probability of inundation generally fall into four categories: levee improvements, upstream transitory storage, diversions, and combinations of these features. Of these features, it was determined that the first increment would be some amount of levee improvement and this is the base for combining additional measures to become the alternatives. Based on preliminary analyses, the other measures did not show significant reductions in stage or flow, had the potential to create hydraulic impacts, or had very large real estate requirements (USACE, May 2013m). Even with some of these additional measures, the stages and flows were not reduced enough to eliminate the need for levee improvements. For purposes of the current study, the following measures were therefore removed from further consideration:

- Upstream transitory storage at various locations
- Wicket gates at several location along the Sacramento River upstream of the American River confluence
- Pocket bypass
- Yolo Bypass widening
- I Street Diversion Structure
- Adjacent levee – seen as a design refinement to use where possible

Below is a list of alternatives developed by combining measures that were carried forward; these are described in greater detail in the following sections (4.2 - 4.3).

- Strengthen levees in place
- Strengthen levees in place with the Sacramento Bypass widening

The alternative including upstream storage on the American River was carried forward for planning purposes and existing information was used for this study.

4.2 Alternative 1: Strengthen Levees in Place

Due to the urban nature and proximity of existing development to the levees within the American River North and South basins, Alternative 1 proposes strengthen-in-place levee remediation. The stated purpose of this alternative is to improve the flood damage reduction system to safely convey flows up to a level that maximizes net benefits including the potential for a levee raise.

Alternative 1 primarily calls for landside strengthening of levees that do not change in-channel geometry or characteristics. These levee fixes involve the construction of levee remediation measures to address concerns such as seepage, slope instability, potential overtopping, erosion, lack of vegetation compliance, and lack of O&M access along the following streams: the American and Sacramento Rivers; the Natomas East Main Drainage Canal (NEMDC); Arcade, Dry, and Robla Creeks; Magpie Creek; the Pleasant Grove Creek Canal (PGCC); and the Natomas Cross Canal (NCC). This alternative combines construction of levee improvement measures while maintaining the present levee alignment in its existing location (aka, strengthen levees in place).

The Natomas Post Authorization Change Report (PACR) proposed levee improvements for the Natomas Basin that consisted of a combination of strengthen in place, adjacent levee, seepage cutoff walls, and seepage berms. The ARCF GRR study assumes that the work identified in the PACR will be completed as stated and proposes that levee raises are all that remain to be evaluated in the Natomas Basin. The levee raise is expected to be constructed within the existing or now expanded levee footprint. There may need to be some additional real estate considerations along the Natomas East Main Drain Canal downstream of the Pump Station (~RM 6.5). The levee would potentially expand on the landside to minimize any hydraulic impacts. See the Engineering Appendix for more information on the footprints of the alternatives.

A crest elevation of the future without-project mean 0.5% (1/200) ACE event plus 3 feet levee profile was compared the current top of levee. Levee raising (except for the Sankey Gap) was identified when the current top of levee fell below this profile. The typical amount of height increases needed is 1 to 2 feet. Plates 31-56 show the water surface elevations for the alternatives, the future without-project condition for both the 10-year and the 200-year events respectively. Plates 9–11 show the locations of levee raising along with erosion protection (Erosion is discussed in Section 8). Table 4-1 shows the extent (length) of levee raising needed per reach.

One reach in the American River North Basin, Magpie Creek, will require more than just strengthen levees in place to reduce the probability of inundation. Additional features for Magpie Creek may include a detention basin, a new reach of levee, and bridge improvements and are called out in Corps' Section 205 Continuing Authorities Program Basis of Design Report (MWH/CH2M Hill, 1999), and refined by the Draft Supplemental Report to the Section 205 Final Detailed Project Report and Environmental Assessment on Magpie Creek (USACE May 2003). These features will be refined during the Preconstruction, Engineering and Design (PED) Phase.

After the analysis was complete and in response to the increasing concerns about USACE projects encouraging development in floodplains (EO 11988), all proposed levee improvements proposed as part of this report for the Natomas Basin have been removed from all of the final alternatives. See the main report for more information.

4.3 Alternative 2: Alternative 1 plus Sacramento Bypass Widening

Alternative 2 starts with Alternative 1 (strengthen levees in place) as a base and adds the widening of the Sacramento Bypass/Weir. The purpose of this alternative is to redirect more floodwaters from the Sacramento River to the Yolo Bypass and thereby reduce the extent of levee repairs required to meet current design guidance for seepage and stability in the project area. Currently, the Sacramento Weir is 1,920 feet wide with 48 wooden gates that are manually removed when the water surface elevation on the Sacramento River at the I Street gage reaches 30.0 feet NAVD88. If the Sacramento Bypass were widened, it would allow more water to flow into it and, therefore, into the Yolo Bypass. This would lower the water surface elevation on the Sacramento River downstream of the confluence with the American River and subsequently reduce the need for levee raising along the Sacramento River in the Pocket area. Table 4-1 shows the extent (length) of levee raising needed per reach for Alternatives 1 and 2.

The widening of the Sacramento Bypass and Weir was analyzed by expanding the width in increments from 500 feet to 3,000 feet to the north. Each width variation included adding gates (identical to the ones already in place) to the new portion of the weir and widening the bypass to the north. Widening the bypass/weir by 1,500 feet was found to be optimal; however a limited amount of levee raising along the Sacramento River downstream of the confluence is still needed.

For the purposes of this analysis the operation of the expanded Sac Weir was originally set to same condition as the rest of Sac Weir by maintaining a water surface elevation at the I-street Gage on the Sacramento River.

In an attempt to minimize additional flows into the Yolo Bypass for frequent events and in coordination with the sponsor, the new portion of the Sacramento Weir is proposed to be activated based on Folsom Releases. The new portion of Sacramento Weir will only operate when flows from Folsom into the American River exceed 115,000 cfs. This would occur for flood magnitudes between 1% (1/100-Yr) ACE event and a 0.5% (1/200-Yr) ACE.

It is assumed that further more detailed analysis would occur during Preconstruction, Engineering and Design (PED).

Table 4-1:Length of Levee Raising Per Reach (miles)							
				Alt 1		**Alt. 2**	
River	Basin	Bank	Reach Length (miles)	Length of Raise (mi)	Average Height (ft)	Length of Raise (mi)	Average Height (ft)
American River	ARN	Right	13.8	E	-	E	-
Arcade Creek	ARN	Right	2.1	0.5	0.5	0.5	1.0
Arcade Creek	ARN	Left	2.1	0.52	1.0	2	1.0
Dry/Robla Creek	ARN	Left	2.0	0.4	.5	0.4	0.5
Dry/Robla Creek	ARN	Right	1.5	-	-	-	-
Magpie Creek	ARN	Left	0.3	0.5	3	0.5	3
Natomas East Main Drain Canal	ARN	Left	3.6	-	-	-	-
American River	ARS	Left	11.5	E	-	E	-
Sacramento River	ARS	Left	14.9	8.1	1.0	1.0	1.0
Natomas Cross Canal	NAT	Left	5.0	R	-	R	-
Natomas East Main Drain Canal	NAT	Right	12.4	R	-	R	-
Pleasant Grove Creek Canal	NAT	Left	3.8	R	-	R	-
Sacramento River	NAT	Left	18.2	R	-	R	-
		Totals	91.2	10.0		2.9	

R - Removed per EO11988 considerations

E - American River Levees Height set to slightly different profile, raises assumed not to be necessary.

5 FLOODPLAIN HYDRAULICS AND FLOODPLAIN DELINEATION

5.1 FLO-2D Model Development

Floodplain mapping was delineated using FLO-2D, a 2-dimensional, finite-difference flood routing model that used breach hydrographs generated from HEC-RAS model runs simulating failures at the various reaches within the Natomas, the American River North and American River South areas. An existing calibrated HEC-RAS model of the Sacramento and American River system (described in Chapter 3) was used to develop the needed breach hydrographs at all seven frequencies [50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5% (1/200-Yr) and 0.2% (1/500)] at each breach location. These breach hydrographs were then used as inflows for the FLO2D model. The FLO-2D Documentation Technical Memorandum (Tetratech, December 2008) provides detailed information on model development. Much of this information was also provided as part of the F3 Hydraulic Technical Documentation. Plate 25 shows the model extents; the resulting floodplains are shown in Plates 26–30.

For Natomas in particular, the basin acts much like a bathtub. As a breach occurs, floodwaters are contained by the surrounding levees and the area fills up (Plate 7). The Natomas Basin is generally not impacted by roadways and other obstructions in modeling large flood events such as a levee breach. Rainfall and interior flooding are also considered insignificant compared to the volume that would be achieved with a levee breach, and therefore were not considered in the development of the with- and without-project floodplains used in the economic analysis.

The project area is represented with two separate FLO-2D models, one for the floodplain north of the American River and one for the floodplain south of the American River. The study area was split into two floodplains primarily because the north and south floodplains have significantly different topographic characteristics. The north floodplain consists of two basins, the Natomas Basin and North Basin, created by surrounding levees and high ground. The south floodplain slopes away from the American River to the south and west, such that breakout flows from the American River flow across and down valley until diverted or confined by the levees along the Sacramento River and other levees. The American River South model and the American River North model (consisting of the North Basin only) were originally developed for the American River Economic Evaluation Report (ERR) study. For the ARCF GRR study, the Natomas Basin has been added to the American River North model.

The following key assumptions were used in the development of the American River North (Including Natomas) and American River South floodplain FLO-2D models:

- **Grid element size: 400 feet.** The goal was to optimize the grid size to ensure reasonable run times while retaining the ability to adequately define floodplain features.

- **Study origin (top left) point: X = 6,670,800 and Y = 1,998,800.** Using a common study origin point allows for different grid systems to be based on the same grid spacing. Models can be merged and enlarged as needed.

- **Grid element elevation based on the FLO-2D Grid Developer System (GDS) interpolation routine with the high and low outlier elevations determined based on the standard deviation difference filtering scheme.** Due to the large amount of point data available from the LiDAR data, the filtering scheme ensures that any low or high outlier points do not unduly influence the final grid elevation.

- **No streets modeled.** Streets are typically used for modeling interior drainage and are not used for riverine flood delineation, especially given the significant volume of water that would overwhelm the streets in the study area.

- **No rainfall on the floodplain modeled.** No information was available to determine the concurrent rainfall events that would occur for the flood events modeled; therefore, a clear sky was assumed at the time of the levee breakouts.

- **Soundwalls along freeways are not modeled.** Soundwalls are not built to the same structural integrity as an engineered floodwall, and it is assumed that the soundwalls would not hold more than 2 to 3 feet of water at a maximum. In most areas having soundwalls, the road embankments are 2 to 3 feet, eliminating the need to separately model the soundwalls. Only the raised roadway embankment was added a barrier for flow in the FLO2D model.

- **Infiltration was not modeled in the FLO-2D models.** This was due to a number of factors including (1) the short duration of the of the initial breakout flow hydrographs, (2) the urban nature of the primary floodplain with limited potential infiltration area, and (3) the probable saturation of the ground from the storm event and preceding storm events, creating a very low to no initial infiltration potential. While any infiltration that does occur will have a noticeable effect on the final floodplain extent and depth (as accounted for in the dewatering analysis), it would not noticeably affect the maximum extent and floodplain depths, which are the focus of this analysis.

- **Existing interior pump stations and discharge points to the American or Sacramento rivers are assumed to be inoperable.** This is partially based on lessons learned from New Orleans during Hurricane Katrina, including such causes as high stages in the respective rivers, direct and backup power failures, submerged equipment damage, etc. that occur when pump stations are overwhelmed and flooded.

5.2 Levee Breach Hydrograph Sensitivity

Levee breach conditions in the HEC-RAS model are dependent on many parameters. A sensitivity analysis was performed to determine how a breach hydrograph is impacted by selection of levee breach elevation, timing of breach, breach formation duration and breach width. Index point B on the American River South Basin (American RM 4) was used for this analysis, which is documented in the Levee Breach Sensitivity Technical Memorandum (USACE, May 2013h).

The changes in peak river stage, peak river flow and breach hydrograph volume were used to evaluate the sensitivity of the selected breach parameters at both the 4% (1/25) and 0.5% (1/200) ACE. Of the three variables, volume is seen as having the greatest impact for floodplain extents and depths. The same levee breach assumptions described in Section 3.5 were used for each levee break scenario (at each index point for each the seven frequencies.)

General trends were observed and are noted below and addition information can be found in the Levee Breach Sensitivity Technical Memorandum.

- Floodplains are not sensitive to changes in levee breach elevations, but are sensitive to the timing of the hydrograph of the flood event.

- Floodplains are not sensitive to breach formation duration, based testing done for the Sutter County Feasibility Study.

- Floodplains are sensitive to breach width during frequent flood events [4% (1/25)] but not infrequent flood events [0.5% (1/200)]. However, many Sacramento Corps feasibility studies generally use infrequent flood events (such as the 1% (1/100) ACE event) based on historical levee breach information. It is also important to have consistent breach widths (500 ft) for the full suite of frequency flood events, so the same breach width was used for frequent and infrequent flood events.

- Floodplains are sensitive to the timing of the breach, particularly when the levee breaches after the peak flow during a flood event (on the receding limb of the river hydrograph). When the breach occurs at the end of a flood event, a smaller floodplain occurs because the amount of water conveyed into the floodplain decreases. The sensitivity to the breach timing is independent of the flood frequency because much of the volume of water in the flood event has already passed by the levee breach location. Thus, even though this parameter affects the floodplain volume, assuming a breach on the receding limb of the hydrograph results in a smaller floodplain extent, and is not considered the most likely condition. Breach formation was therefore assumed to occur on the rising limb of the hydrograph to reflect the most likely flooding condition in each damage area.

The conclusion from this sensitivity analysis is that, for the purposes of the feasibility study, the assumptions used for the levee breaches are appropriate for use in the economic analysis.

5.3 With-Project Floodplains

For the with-project floodplains, the without-project condition floodplains were used with adjustments made to the frequency of the floodplains.

To approximate each with-project floodplain, the with-project breach hydrographs were compared to the corresponding without-project breach hydrographs. Peak flow and volume were the variables used to compare the two levee breach hydrographs. For each alternative and at each index point, the following comparison was made for each of the seven frequencies:

- If the change between without- and with-project breach hydrograph volumes were within 10%, then the without-project levee breach hydrograph and corresponding floodplain could be substituted for use as the with-project levee breach hydrograph and corresponding floodplain.

- If the change in volume was greater than 10%, then the without-project levee breach hydrograph and corresponding floodplain from the next largest flood event were evaluated based on the same threshold. If that comparison failed, the process was repeated with increasingly large flood events until a substitute event was found that met the threshold. For example, the 10-yr with-project levee breach hydrograph was compared to the 10-yr without-project levee breach hydrograph at each index point and if the volume differed by greater than 10%, the 10-yr with-project levee breach hydrograph was then compared to the 25-yr without-project levee breach hydrograph. If the volume again differed by greater than 10% for that comparison, the 10-yr with-project levee breach hydrograph was then compared to the 50-yr event and so on until the threshold was met.

Table 5-1 shows the specific changes in Annual Chance Exceedance (ACE) used to adjust the floodplains from the without-project condition to with-project conditions. The shaded areas in the table represent where a without-project floodplain from a different frequency was used for the with-project floodplain for each alternative.

Table 5-1 Alternative Floodplain Key

Future Without Project / Alt. 1: Strengthen in Place								
Basin	**Index Point**	**2-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**200-yr**	**500-yr**
ARN	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARN	E	-	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	F	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
NAT	D	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
Alt. 2: Alt. 1 +Sacramento Bypass Widening								
Basin	**Index Point**	**2-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**200-yr**	**500-yr**
ARN	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARN	E	-	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	A	-	-	25-Yr	50-Yr	100-Yr	200-Yr	500-Yr
ARS	F	2-yr	10-yr	25-Yr	50-Yr	100-Yr	100-Yr	500-Yr
NAT	D	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr

6 RISK ANALYSIS

Inputs were generated for risk analysis from the hydraulic modeling. The Hydrologic Engineering Center's Flood Damage Assessment modeling software (HEC-FDA) is the principal tool used by the Corps to calculate flood damage risks. The HEC-FDA model performs Monte Carlo random sampling of the discharge-frequency, stage-discharge, stage-probability of failure, and damage-stage relationships and their respective uncertainty distributions. The primary outputs of HEC-FDA are expected annual damage (EAD) and project performance statistics. Project performance statistics include the annual exceedance probability (AEP, or the expected annual probability of flooding in any given year), the long-term risk of flooding over a 10-, 25-, or 50-year period, and the conditional non-exceedance probability (CNP) for specific Annual Chance of Exceedance (ACE) events (the probability of passing specific ACE flood event).

Recent guidance has come out that provides a means for more explicitly performing a risk analysis in a system setting such as the Sacramento River (HEC, 2009). Some processes derived from this new guidance were implemented in generating inputs for the HEC-FDA analyses. The guidance was based upon a demonstration project using the Sacramento River system and an earlier version of the HEC-RAS Common Features model. The work was done by West Consultants, Inc., for the Hydrologic Engineering Center (HEC). Some values derived from the study are therefore directly applicable to this study. A similar assessment was conducted by MBK Engineers and David Ford Consulting Engineers (MBK Engineers, 2009 and David Ford, 2009) for the Sacramento Area Flood Control Agency (SAFCA). Information derived from these reports including FDA models including uncertainty values from HEC and the updates from the follow on applications of the policy by the local sponsor (SAFCA) was considered and used in developing the inputs for the West Sacramento GRR study.

6.1 Index Points

Hydraulic results are available at each cross section in the HEC-RAS model. For economic purposes, a single point is needed to represent each reach and is often referred to as an index point. The levees surrounding Sacramento, already separated by a waterway, are further divided into reaches represented by similar geotechnical conditions, as described in the geotechnical report. Each reach was originally represented by a single index point located at the same position as the geotechnical fragility curve.

Data is generated at representative index points within each reach and are used to estimate project performance statistics under both without-project and with-project conditions. The engineering data is also used in conjunction with economic data to estimate expected damages and benefits. Both sets of results are then used together to describe the flood risk in the study area.

Twenty-five reaches were originally identified based on extensive geotechnical analyses of the levee conditions along each source of flooding within the study area. From these 25 reaches, the project delivery team (PDT) selected five of them, each containing one index point, for which to generate engineering data for use in the economic modeling and the associated without-project damage and with-project benefit analyses. They are also listed in Table 6-1.

Table 6-1. Index Points

Index Point	Basin	Index Point	Project Reach	River Mile
American River North Levee	ARN	A	American River	7.8
Arcade Creek North Levee	ARN	E	Arcade Creek	0.9
American River South Levee	ARS	A	American River	8.9
Sacramento River South	ARS	F	Sacramento River	50.3
Natomas Cross Canal South Levee	NAT	D	Natomas Cross Canal	2.7

The PDT also selected three additional index points -- two located on the right and left banks of the American River and one located on the NEMDC/PGCC (also known as the Sankey Gap) at locations where there are no levees. These index points were not part of the original 25, but were included in order to aid in a more accurate description of residual flood risk in the study area.

The representative index points used in economic analysis were selected based on preliminary estimates of the chance of flooding and consequences of flooding using flood plain extents and depths, levee fragility (geotechnical fragility curves), and estimates of ACE event damages.

In this analysis "representative index points" refers to those locations whereby the without-project condition (damages and performance) of the study area is best characterized. The PDT's intent was to balance rigor with practicality in choosing the number of index points to use in the analysis. Once the number of index points was determined for this GRR – essentially one index point to represent a major source of flooding (per bank side) plus several others to be able to check for residual damages (e.g., outflanking locations on the American River), the PDT then made a preliminary comparison of the chance of flooding and the consequences of flooding – in other words the overall flood risk associated with a levee breach at various locations – in selecting the representative index points. During the course of the study, two of the index points (ARS B and ARS E) that were originally selected were replaced by alternate index points (ARS A and ARS E).

6.2 Stage-Discharge Frequency Curves

Peak stage data for all index points was derived for the 10% (1/10) ACE through the 0.2% (1/500) ACE events in the same manner for both with- and without-project conditions. Results were taken directly from the HEC-RAS model runs. However, the 99.9% (1/1.001) ACE and the 50% (1/2) ACE stage data was derived via a different process using gage data, and is further discussed in the Risk Analysis Technical Memorandum (USACE, May 2013i). The use of flow-frequency and stage-discharge relationships in HEC-FDA is preferable; however, currently HEC-FDA requires an increasing flow value for an increasing stage value (in this case a stage-frequency relationship must be used). For index points ARN A, ARS B, and ARS E, flow-frequency and stage-discharge relationships were generated for the HEC-FDA analysis (see Plate 8 for location of index points). A stage-stage relationship similar to a stage frequency relationship was used for ARN E and NAT D due to backwater effects.

6.3 Uncertainty

6.3.1 Hydraulic Uncertainty

Following guidance in Engineer Manual EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies," the performance and reliability of the project features were assessed with an uncertainty-based analysis. The stage uncertainty parameter in HEC-FDA is used to account for uncertainties in the calculated water surface elevations. These uncertainties can be attributed to accuracy and precision of the topographic data, hydraulic computational assumptions (roughness coefficients and bridge debris loading), sedimentation and operations (gates/pumps) and other potential factors. The total uncertainty from these attributes is a combination of the following factors from EM 1110-2-1619: natural variations, model uncertainty, sedimentation, and operations factors. Table 6-2 has the total stage uncertainty for each index point for the suite of frequencies. See the Risk Analysis Technical Memorandum (USACE, May 2013i).

Table 6-2: Total Stage Uncertainty (One Standard Deviation), Feet						
River		American	Arcade	American	Sacramento	Natomas Cross Canal
Index Point		A	E	A	F	D
RS		7.83	0.95	8.90	50.25	2.71
Basin		ARN	ARN	ARS	ARS	NAT
Percent Annual Chance Exceedance	50%	0.97	0.85	1.00	0.75	0.85
	10%	1.23	0.90	1.29	0.77	0.92
	4%	1.38	0.93	1.45	0.76	1.03
	2%	1.38	0.95	1.45	0.76	1.04
	1%	1.36	0.93	1.43	0.76	0.98
	0.50%	1.53	0.86	1.59	0.75	0.84
	0.20%	0.76	0.75	0.75	0.78	0.75

6.3.2 Hydrologic Uncertainty

For index points along the Sacramento River (ARS E), Natomas Cross Canal (NAT D) and Arcade Creek (ARN E), the flow frequency analysis is based on a graphical method. The period of record (equivalent years of record) for index points NAT D and ARN E is 71 years and period of record for index point ARS E is 73 years. The period of record was chosen based upon the HEC report for the systems risk and uncertainty analysis (HEC, 2009). Results from locations closest to index points were used. Values for Arcade Creek were taken from the SAFCA 408 Request (MBK, June 2009), which is based on EM 1110-2-1619.

The index points along the American River (ARN A & ARS B) are based on analytical flow frequency analysis. The input statistics for FDA analysis are shown in Table 6-2.

Table 6-3: American River at Fair Oaks (1905-2004)
Adopted Unregulated Inflow Statistics

Log Mean	4.581
Log Std Dev	0.43
Log Skew	-0.077
Equivalent Record Length (yrs)	100

6.3.3 Inflow-Outflow Uncertainty

The purpose of the inflow-outflow curves is to translate unregulated flow-frequency curves and uncertainty to the regulated condition. It also provides an additional means of accounting for hydrologic uncertainty within the system, recognizing that flow entered into the upstream ends of the system attenuates. How much it attenuates depends in large part upon the capacity of the river or levee system. Inflows correspond to the analytical and graphical inflow frequency curves in FDA (Reference f). The outflows were taken from standard HEC-RAS output tables at each index point. Inflow-outflow curves were generated for both with-project and without-project conditions assuming no upstream levee failures. Uncertainty for the inflow-outflow curve was based on work done in the Natomas Post Authorization Change Hydraulics and Hydrology Appendices.

6.4 Flood Damage Modeling

In addition to the no-levee-failure model runs, flood damage assessment was done by simulating the flow of water from a levee failure into each basin. Levee failures were simulated for each reach using seven frequencies (50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5%(1/200), 0.2%(1/500) ACE) to generate a stage-damage relationship for each reach for the economic analysis. As described in Section 5.2, levee failure runs were made only using the without-project condition. Plates 65 through 69 contain the water surface elevations at the project index points for the full suite of frequencies and the following conditions and alternatives:

- Future without-project condition
- Alternative 1: Strengthen in place
- Alternative 2: Strengthen in place with Sacramento Bypass widening

A summary of the key results are described below:

- For all index points, there are no significant changes in stage or flow between the future without-project condition and the Strengthen Levees in Place Alternative 1.
- As expected, there are reductions in stage and flow on the Sacramento River Reach below the confluence with the American River (at ARS E) when Alternative 2 is compared to the future without-project condition.
- The results for Natomas Index Point D, located on the Natomas Cross Canal, are similar for all conditions.

6.4.1 Upstream Levee Performance

As part of the CF GRR F3 analysis, upstream levee performance was considered in a sensitivity analysis (USACE, 2009e). A single index point at Verona (just downstream of the Natomas Cross Canal and Sacramento River confluence) was tested using historical data. The analysis showed that there was no significant influence on the stage and resulting expected annual damages from upstream levee performance. Based on this information, a decision was made to proceed with analyses assuming no upstream levee failures. All work under the American River Common Features GRR assumes no upstream levee failures.

6.5 Performance Evaluation

Future without-project annual exceedance probability (AEP) was computed on a reach/index point-specific basis using the HEC-FDA model. The HEC-FDA model integrates the hydrologic, hydraulic, geotechnical and economic relationships with uncertainty to create exceedance probability-damage functions with uncertainty.

The annual exceedance probability (AEP) represents the percent chance of a target stage being exceeded in any given year, thereby causing flooding and subsequent significant property damage. The annual exceedance probability results for each damage area are computed by HEC-FDA based on specific engineering data: frequency-stage curve, equivalent record length, and top-of-bank stage.

The AEP results were used to establish the future without-project expected annual damages (EAD) to determine economic benefits and evaluate performance of the alternatives. Table 6-4 shows the results of the levee performance evaluation for each index point in the project area. The 0.5% assurance values are a linear interpolation of HECFDA results between the 1% and 0.4% Assurance values. The future without project condition is included in Table 6-4 because it is the basis of comparison for the alternatives; this is discussed in greater detail in Section 2.2. More information about the economic benefits and expected annual damages can be found in the economic appendix.

Table 6-4: Performance at each Index Point

	Basin	ARN	ARN	ARS	ARS	NAT
	Index Point	A	E	A	F	D
	River	American	Arcade	American	Sacramento	NCC
	River Station	7.8	0.9	8.9	50.3	2.7
FWOP	Annual Exceedance Probability (AEP)	0.010	0.017	0.011	0.031	0.009
	1/AEP	96	61	93	32	108
	1% Assurance	75%	54%	76%	69%	84%
	0.5% Assurance	47%	29%	45%	55%	58%
	0.2% Assurance	22%	7%	18%	24%	37%
Alt. 1	Annual Exceedance Probability (AEP)	0.006	0.005	0.005	0.007	0.006
	1/AEP	182	200	185	135	159
	1% Assurance	90%	94%	91%	95%	84%
	0.5% Assurance	59%	69%	64%	93%	56%
	0.2% Assurance	24%	23%	31%	89%	27%
Alt. 2	Annual Exceedance Probability (AEP)	0.006	0.004	0.005	0.007	0.006
	1/AEP	172	256	192	147	164
	1% Assurance	89%	95%	91%	95%	85%
	0.5% Assurance	57%	80%	60%	94%	57%
	0.2% Assurance	22%	28%	32%	81%	28%

6.6 Considerations and Assumptions

The results of the risk analysis are affected by technical considerations and assumptions regarding the inputs to HEC-FDA. For example, geotechnical studies developed relationships that characterize the reliability of the levees. Perhaps the most significant assumption is the levee failure methodology, which can significantly influence simulated breach hydrographs. These assumptions are described in Section 3.5 and were also evaluated in a sensitivity analysis in the Levee Breach Sensitivity Technical Memorandum (USACE May 2013h). The methodology chosen provides a conservative and consistent simulation of the potential flooding extent for system-wide hydraulic and economic evaluations. It does not necessarily represent conditions during an actual flood event, when flood fighting and other emergency actions are likely to take place.

6.7 FEMA Certification/Accreditation

The Engineering Circular 1110-2-6067 serves as guidance for USACE to provide the necessary Risk and Uncertainty (R&U) rationale to certify/accredit levees for FEMA. FEMA certification was not determined at this time. The local sponsor has an interest in having the strengthened levees meet the minimum requirements needed for FEMA accreditation. By traditional FEMA methodology (Title 44 CFR Section 65.10), it is likely that the local sponsor could achieve FEMA Certification in all three basins using this proposed project, recent projects (Natomas PAC) and the locals' ongoing efforts under the Natomas Levee Improvement Program (NLIP). If the sponsor conducted the certification, they would have to meet the requirements of Title 44 CFR Section 65.10. If USACE performed the certification, they would have to meet additional requirements described in EC 1110-2-6067. At a minimum during design, the locally preferred plan will have a top of levee profile that would be set to meet the minimum height requirements as defined in Title 44 CFR Section 65.10

The Engineering Circular 1110-2-6067 serves as guidance for USACE to provide the necessary Risk and Uncertainty (R&U) rationale to certify/accredit levees for FEMA. FEMA certification was not determined at this time. The local sponsor has an interest in having the strengthened levees meet the minimum requirements needed for FEMA accreditation. By traditional FEMA methodology (Title 44 CFR Section 65.10), it is likely that the local sponsor could achieve FEMA Certification in all three basins using this proposed project, recent projects (Natomas PAC) and the locals' ongoing efforts under the Natomas Levee Improvement Program (NLIP). If determined to be needed, this additional analysis will most likely be conducted during refinement of the selected alternatives (including a possible locally preferred plan) or during the design phase. If the sponsor conducted the certification, they would have to meet the requirements of Title 44 CFR Section 65.10. If USACE performed the certification, they would have to meet additional requirements described in EC 1110-2-6067. At a minimum this would be likely be completed by ensuring that there is 3 three feet of freeboard above the 1% (1/100) ACE for all the levees in the project area.

6.8 Urban Levee Design Criteria (ULDC)

Urban Levee Design Criteria (ULDC) is a state standard established by the CA Dept of Water Resources where from a hydraulic perspective; urban levees are required to have at least 3' feet of free board above the mean 200-Yr event or a combination of freeboard (2-3) and assurance (90%-95%) to contain the mean 200-Yr event.

The State has established a standard for urban flood protection in California which applies to cities with populations greater than 10,000 inhabitants. This standard requires levees to withstand flows with a top elevation equal to the mean 200-year water surface profile, plus three feet of freeboard, plus an allowance for wave run-up, plus one foot to account for climate change. USACE does not identify a target level of risk reduction but rather identifies the plan which reasonably maximizes net benefits. The analysis to identify the plan which maximizes net benefits was done with an awareness of the State's goal for urban flood protection for the purpose of informing the State of where the individual plans fall with regards to the State's standards. Neither of the final alternatives is currently able to contain a 1/200 ACE event with 90% assurance. The levee improvements along the Sacramento River will increase the assurance to a level close to 90% but the assurance for the levees along the American River will remain lower than the ULOP criteria for the 1/200 ACE. However, the locally preferred plan will meet the minimum height requirements as described in the ULDC. It will be contingent upon the local community to prove to the State that the aggregate flood risk management projects meet the State's standard.

6.9 Systems Risk and Uncertainty

Each of the final alternatives included setting the top of levee profile at the 0.5% (1/200) ACE plus 3 feet (except for Sankey Gap), and a systems risk analysis was conducted to determine if there are hydraulic impacts from this levee raising. A process for evaluating system-wide hydraulic impacts of proposed modifications to the levees of the Sacramento River Flood Control Project (SRFCP) has been developed by the Hydrologic Engineering Center (HEC) and further information can be found in their "Documentation and Demonstration of a Process for Risk Analysis of Proposed Modifications to the SRFCP Levees" report. The process utilized risk analysis methods that followed USACE policy as outlined in ER 1105-2-101. The Systems Risk Technical Memorandum (USACE, May 2013l) further details the application of this ER and HEC guidance to this study. The system wide risk analysis method defined by HEC was considered applicable to the ARCF GRR study.

A key assumption of the system-wide risk analysis is that risk of a levee failure is associated with overtopping only. Levee fragility curves are not used in this analysis and levees are assumed to convey water to the top of levee throughout the system. This assumption is based on USACE Letter on Guidance on System Risk for modifications to Corps of Engineer Projects (USACE, July 2008).

The purpose of this evaluation was to determine if potential system-wide impacts can be identified based on the increase in annual exceedance probability (AEP) or a decrease in conditional non-exceedance probability (CNP, also referred to as 'assurance') within the FDA model. Using the model HEC created for the Sacramento River Flood Control Project (SRFCP) levees, new plans were created for each of the four scenarios. The following four scenarios were analyzed:

- Future without-project baseline condition
- Alternative 1: Strengthen in place
- Alternative 2: Strengthen in place with Sacramento Bypass widening

Potential impacts are identified when an increase in the AEP and a reduction in CNP occur at locations throughout the system when compared to the hydraulic baseline condition. The median AEP is computed directly from the inflow discharge-exceedance probability, the inflow-outflow and stage-discharge relationships that are defined at each index location. The expected AEP incorporates uncertainty in these relationships. Typically, an increase in water surface elevation without a change in the levee height will result in an increase in AEP and a reduction in CNP, which indicates an increase in the level of risk.

The following changes in AEP and CNP were identified based on comparison of the two alternatives and the two baseline conditions:

- There was no significant change in median overtopping AEP
- There was no significant change in expected overtopping AEP (rounded at three significant figures)
- There are small changes in the overtopping CNP/assurance, mostly in the thousandths place.

6.10 Potential Hydraulic Impacts to the Yolo Bypass

The proposed project features main purpose is to reduce flood risk in the project area. Hydraulic Impacts outside of the project area as result of these features being implemented have to be disclosed and possibly accounted or mitigated for in this study. With the widening of the Sacramento Bypass, there was added attention to how this widening would impact the Yolo Bypass.

From the executive summary HEC's PR-71 document:
"The potential impacts defined from deterministic analysis results are changes in water surface elevation and freeboard that are defined in units of length such as feet. Due to the common use of length units in everyday affairs, the significance of differences expressed in units of length are generally well understood. In contrast, the potential impacts defined from risk analysis results are changes in probabilities. In general, the significance of differences in probabilities, particularly small differences in probabilities, are difficult to conceptualize. Consequently, a need exists for development of guidance or criteria to define the significance of risk analysis results."

For purposes of this analysis, the definition of a potential hydraulic impact was defined as a change in water surface elevation. With the advent of risk and uncertainty, guidance is lacking on what constitutes a significant impact though changes in stage on the order of 0.1 feet to 1.0 feet are often used as a threshold.

The hydraulic baseline is the future without-project condition where most of systems exist as it is today and includes the recent and in-construction Folsom improvements (including the JFP) in place.

For with-project conditions, the peak releases from Folsom Dam for the 1% (1/100) ACE and 0.5% (1/200) ACE events are 115,000 cfs and 160,000 cfs. This amount of flow continues on down the American River to the Sacramento River. Flow conditions splits for the 10% (1/10) ACE, 1% (1/100) ACE, and 0.5% (1/200) ACE events are depicted on the Sacramento-American River Confluence Plates 70-72.

With the widening of the Sacramento Weir and Bypass and for when flows exceed 115,000 cfs on the American River, some of the American River flow that would have gone downstream on the Sacramento River is instead drawn upstream to the widened Sacramento weir.
To determine if there are potential hydraulic impacts in the Yolo Bypass, stages the future without-project condition were compared with the stages from Alternatives 1 and 2. The additional water that

would flow through the weir and into the Sacramento Bypass could raise water surface elevations in the Yolo Bypass up to 0.11 feet for the 0.5% (1/200) ACE and 0.8 feet for 0.2% (1/500) ACE event. This increase is considered less than significant because it would not change land uses, require additional levee remediation, and is not expected to significantly increase flood risk. For a 0.2% (1/500) ACE event, many areas are subject to inundation from overtopping or other levee failure mode. Tables 6-6 and 6-7 contain water surface elevations at Yolo Bypass stream gages upstream and downstream of the Sacramento Bypass. It is assumed that further more detailed analysis would occur during Preconstruction, Engineering and Design (PED) to further reduce any increase in water surface elevation.

Given the geographic connection of the current ARCF project and several ongoing American River projects (JFP Spillway, Natomas PAC, WRDA 96/99 Sites), there was a rationale to evaluate the individual projects together as a single project to evaluate hydraulic effects or impacts. Many of the projects are tied to the larger single American River Watershed Investigation study that occurred in the early 1990s. After significant discussion, this idea of separating the hydraulic baseline from the economic baseline was abandoned.

Table 6-5. Water Surface Elevation Summary for the Yolo Bypass at the Woodland Gage (RM 50.9).

Water Surface Elevation Summary				
Yolo Bypass at the Woodland Gage(RM 50.9)				
Frequency	FWOP	Alt. 1 Strengthen in Place	Alt. 2 Sac Bypass	FWOP - Alt. 2
	NAVD88	NAVD88	NAVD88	NAVD88
2-Yr	26.6	26.6	26.6	0.00
10-Yr	30.2	30.2	30.2	0.00
25-Yr	32.9	32.9	32.9	0.00
50-Yr	33.7	33.7	33.7	0.00
100-Yr	34.7	34.7	34.7	0.00
200-Yr	36.6	36.6	36.7	0.05
500-Yr	37.3	37.3	38.0	0.77

Table 6-6. Water Surface Elevation Summary for the Yolo Bypass at the Lisbon Gage (RM 35.7).

Water Surface Elevation Summary				
Yolo Bypass at the Lisbon Gage (RM 35.7)				
Frequency	FWOP	Alt. 1 Strengthen in Place	Alt. 2 Sac Bypass	FWOP - Alt. 2
	NAVD88	NAVD88	NAVD88	NAVD88
2-Yr	19.7	19.7	19.7	0.00
10-Yr	24.5	24.5	24.5	0.00
25-Yr	27.0	27.0	27.0	0.00
50-Yr	27.7	27.7	27.7	0.00
100-Yr	28.6	28.6	28.6	0.00
200-Yr	29.6	29.6	29.7	0.11
500-Yr	30.7	30.7	30.7	-0.02

7 RESIDUAL RISK

Several methods and types of analysis are used to describe the hydraulic impacts and residual risk of the proposed alternatives. They are described below.

7.1 Residual Risk

Residual risk is the risk of being inundated after the selected alternative has been implemented which can include residual risk associated with the project features, residual risk from physical conditions not related to project features, and residual risk from an event exceeding the design of the system. Residual flood risk after completion of the selected plan would vary throughout the study area. The levees in the project area have not been designed for overtopping with the exception of the Sankey Gap in Natomas.

The residual risk associated with project features is captured by the with-project fragility curves and floodplains, and is covered in Chapters 4 through 6 of this report. The residual risk floodplains were developed using HEC-RAS and FLO-2D, and provided to the Economics Section to be included as part of the overall net benefit calculation. Additional information on Risk can also be found on the Economic Appendix.

The residual risk from both project features and physical conditions not related to project features are reflected in the residual floodplains for each of the three basins (Plates 62-64). The residual risk for each basin is described below.

The three primary sources of residual flood risk for the Natomas Basin would be:

-Overtopping Flows from the Sankey Gap.

-Infrequent large flood events [greater than 0.5% (1/200) ACE] that overtop the project levees.
-Unforcasted geotechnical failure of the project levees [mostly for events greater 1% (1/100) ACE]

In the Natomas basin, the Sankey Gap is located in the northeastern corner of the basin between the Pleasant Grove Creek Canal and the Natomas East Main Drain Canal (see Plate 7). The Sankey Gap is a hardened overtopping weir built to handle flow from ponded water that flows into the basin. During a flood event on the Sacramento River, water will pond on the northeastern exterior edge of the Natomas Basin and then back up small creeks along the Pleasant Grove Creek Canal and eventually flow through this hardened weir. The height of the ponded water at the Sankey Gap is tied directly to stages in the Sacramento River, and flow through the Sankey Gap was observed in the 1986 and 1997 flood events. Plate 62 show the 0.2% (1/500) ACE residual floodplain based on overtopping from the Sankey Gap. There are no plans to change the operation of this feature to reduce the residual risk.

An overtopping flood event would likely be preceded by flood warning and river guidance issued by the National Weather Service (NWS) and California Nevada River Forecast Center (CNRFC) five days in advance. A more accurate warning would likely be made 24 to 36 hours in advance. Overtopping Risk could come from any of the levees along the Sacramento River, American River, Natomas East Main Drain Canal (NEMDC), Natomas Cross Canal (NCC), and Please Grove Creek Canal. The likely first overtopping locations would be along the Sankey Gap and parts of the NEMDC where the volume of water is significantly less than in the American or Sacramento Rivers.

The Natomas Basin Levees does have some superiority built into them by way of the Fremont Weir and the Sutter-Yolo Bypass. Much of the water(approx. 75%) coming down the Sacramento River Flood Control Project goes over the Fremont Weir just upstream of the Natomas Basin. Given that the Sacramento River and Natomas Cross Canal were both strengthened (as part of Natomas PACR and SAFCA Natomas 408) raised (SAFCA's 408), it is very likely the other parts of the system would begin to overtop before these levees. The American River water is limited by both flows out of Folsom and channel capacity as described more in the next section on the other two basins in the project (ARN and ARS). However, any failure of the levee system surrounding Natomas will continue to have consequences given the large population and deep floodplains with depths greater than 20 feet for breaks along the Sacramento River, American River and the lower portions of the NEMDC. The extents of the floodplains for the unforcasted geotechnical failure would be similar to the without project floodplains found on Plates 30.

The two primary sources of residual flood risk for the American River North and American River South Basins would be:

-Infrequent large flood events [greater than 0.5% (1/200) ACE] that overtop and outflank the channel upstream from the leveed system.
-Unforcasted geotechnical failure of the project levees [mostly for events greater 1% (1/100) ACE] mostly driven by a risk of erosion failure due to high velocities in the American River.

An overtopping flood event would likely be preceded by flood warning and river guidance issued by the National Weather Service (NWS) and California Nevada River Forecast Center (CNRFC) five days in advance. A more accurate warning would likely be made 24 to 36 hours in advance. Plates 63–64 only contain the 0.2% (1/500) ACE residual floodplains for the two basins as it is assumed that the channel will be able to hold up to a 0.5% (1/200) ACE coming out of Folsom after completion of the Joint Federal Project Auxiliary Spillway and levee improvements along the American River. This assumption is based on the auxiliary spillway's ability to control flows out of Folsom up to the 0.5% (1/200) ACE. The extents of the floodplains for the unforcasted geotechnical failure would be similar to the without project floodplains found on Plates 26 and 28.

The American River Levees have superiority built in by this channel outflanking as there is a maximum amount of water that continues down the channel with the excess flow leaving the system in a somewhat calmer manner than a levee break.

In the American River South Basin, the Sacramento River has strengthened levees and superiority is built in by the use of the Sacramento Weir and Bypass that divert high flows away from the Sacramento and out into the Yolo Bypass. The use of weirs to help with superiority follows ETL 110-2-299. Alternative 2 enhances this feature by widening the Sacramento Weir and Bypass allowing more water to be diverted away from Sacramento.

According to ETL 1110-2-299, "Overtopping of Flood Control Levees and Floodwalls," two design types can be used to control initial overtopping. The first is the use of different levee heights relative to the design water surface from reach to reach to force overtopping in a desired location. The second design uses notches, openings, or weirs in the structure. The inverts for these features are at or above a design water surface elevation but below the neighboring top of levee. Examples are railroad or road crossings of levees and rock weirs.

For the areas described above, the residual risk associated with project features, and physical conditions not related to project features is assumed to be the same for the final array of alternatives. The levee improvements and possible Sacramento Bypass widening do not significantly change the hydraulic conditions on the American River upstream of the leveed section or the northern part of the Natomas basin.

7.2 Climate Change – Hydrology

A sensitivity analysis was conducted to assess the impact of climate change for the American River Common Features GRR. Studies have shown that increasing temperatures associated with climate change are causing a shift in the runoff patterns of Pacific slope watersheds with a large snowmelt component. The runoff shifts for those watersheds include increased runoff in winter, less snowmelt in summer, and earlier runoff in the spring (USACE, 2011b).

The methodology for the climate change sensitivity analysis of runoff peaks and volumes was developed by the Sutter Basin Pilot Study, and this method was applied to the American River Common Features Study. The Sutter team made further refinements to this method, but because the refinements yielded results similar to the first attempt, the ARCF PDT continued to use the results of the first method. The approach is summarized below, and more details on the application of this method can be found in the Climate Change Technical Memorandum (USACE, May 2013b).

The present-condition hydrology in the study was assumed to be representative of 2009 conditions. For future-condition hydrology scenarios, results from a University of California, San Diego study on Sierra Nevada runoff (UCSD, 2011) were interpolated and extrapolated to determine the percent difference of the 4% (1/25), 1%(1/100), 0.5%(1/200), 0.2%(1/500) ACE events. The return period was plotted as a function of the percent difference, and a logarithmic curve was fit to the graph. The resultant estimated climate change differences from the study presented in Table 7-1 were used to translate the frequency of the water flowing into the various reservoirs in the Sacramento River system.

Table 7-1. Climate Change Differences for Northern Sierra Nevada, WY 2049

% Difference in 3-day Unregulated Flow			
Frequency	CNRM CM3	GFDL CM2.1	NCAR PCM1
1/2	12	22	6
1/5	16	23	-4
1/10	21	27	-10
1/20	27	32	-14
1/50	35	40	-19
1/100	35	40	-19
1/200	35	40	-19
1/500	35	40	-19

Global Climate Change Models:

CNRM CM3: French National Centre de Recherches Meteorlogiques Climate Models.

GFDL: Geophysical Fluids Dynamics Laboratory model version 2.1

NCAR PCM 1: National Center for Atmospheric Research Parallel Climate Model

A sensitivity analysis was conducted at two locations in the study to evaluate the effect of climate change on regulated flows: at the American River Fair Oaks gage and at the Sacramento River Verona gage. The analysis was performed by applying the changes shown in Table 7-1 to the unregulated flow-frequency curves at the two locations. Reservoir operations were assumed to remain the same for future conditions, and therefore inflow-outflow relationships would not change. The translation of regulated flows was made graphically with more information on this process found in the Climate Change Technical Memorandum (USACE, May2013b). Tables 7-2 and 7-3 show the future regulated flows and anticipated annual chance of exceedance (ACE) for both index locations.

Table 7-2. Change in Frequency of Flows with Climate Change at American River Fair Oaks

Climate Model		CNRM CM3	GFDL CM2.1	NCAR
Present Regulated Frequency and Flow		Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049
ACE	Flow (cfs)	ACE	ACE	ACE
½	26,000	1/2	1/2	1/2
1/10	72,000	1/7	1/7	1/13
1/25	115,000	1/17	1/14	1/39
1/50	115,000	1/25	1/25	1/83
1/100	115,000	1/48	1/40	1/167
1/200	160,000	1/83	1/71	1/385
1/500	224,000	1/200	1/167	1/1000

Table 7-3. Change in Frequency of Flows with Climate Change at Sacramento River Verona

Climate Model:		CNRM CM3	GFDL CM2.1	NCAR
Present Regulated Frequency and Flow		Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049
ACE	Flow (cfs)	ACE	ACE	ACE
½	70,000	1/2	1/2	1/2
1/10	93,000	1/6	1/6	1/14
1/25	110,000	1/13	1/13	1/50
1/50	113,000	1/20	1/20	1/111
1/100	120,000	1/33	1/33	1/250
1/200	130,000	1/56	1/56	1/500
1/500	155,000	1/125	1/111	---

Climate change may also have an effect upon the levees, where a levee raise might be needed to maintain a desired levee performance. While the project will be constructed to maintain a design flow rate, this sensitivity analysis estimates a new frequency for overtopping. The levee crest elevation for future conditions was set at a 0.5% (1/200) ACE event stage plus 3 feet. This new top of levee was compared with present levee crest heights. For the American River Fair Oaks, it appears that there is no overtopping concern needed in response to climate change. However, for the Sacramento River Verona gage, it appears that the left levee crest would have a potential overtopping concern and would need to be raised an average of 3 feet and the right levee crest will need to be raised by 3.5 feet to provide the same performance in response to climate change. The current alternatives have an average levee height raise of 1-2 feet, so to maintain the same performance this average height raise would need to be doubled to account for the estimated effects of climate change along the Sacramento River reach.

The analysis described above should be considered a sensitivity analysis, not a rigorous analysis of climate change using snowmelt hydrology models, reservoir operations models, and river routing models. The State of California is developing a state-wide approach to climate change with a system-wide historical record for unregulated conditions (no reservoirs) along with one regulated condition (with reservoirs). Some of the preliminary data from that state-wide approach was used in this analysis, but the final results are not currently available for use in the ARCF GRR study.

7.3 Sea Level Rise

A second aspect of climate change is sea level rise. Rising sea levels have been observed at locations around the world, and the rate is expected to continue at the current level or increase in the future (IPCC, 2007). Increases in sea level can have a variety of impacts on coastal areas, including flooding, changing ecosystems, and declining water quality. Local subsidence can also cause a greater apparent sea level rise. To analyze potential effects on the Sacramento River system from these changes, several sea level rise scenarios were developed for 50 and 100 years. A subsidence rate was also applied to the low and high 100-year sea level rise scenarios.

Three sea level rise scenarios were developed based on the information contained in EC 1165-2-211, Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs (USACE, 2009). Following the method described in EC 1165-2-212, values for low, intermediate, and high sea level rise rates were developed for 50 and 100 years. The information describing the application of EC 1165-2-211 came from an existing report developed for USACE for work on the Sacramento-San Joaquin Delta (Dynamic Solutions, 2011) and a summary of that information is provided below.

7.3.1 Low Sea Level Rise-

Following guidance outlined in EC 1165-2-211, the low sea level rise scenario was developed using historically measured data at the San Francisco tide gage. EC 1165-2-211 suggests using a tide gage with a minimum of 40 year period of record. The San Francisco tide gage period of record begins in 1897, which is more than sufficient to see long term patterns. Figure 7-1 shows the sea level trend at San Francisco with the seasonal cycle removed.

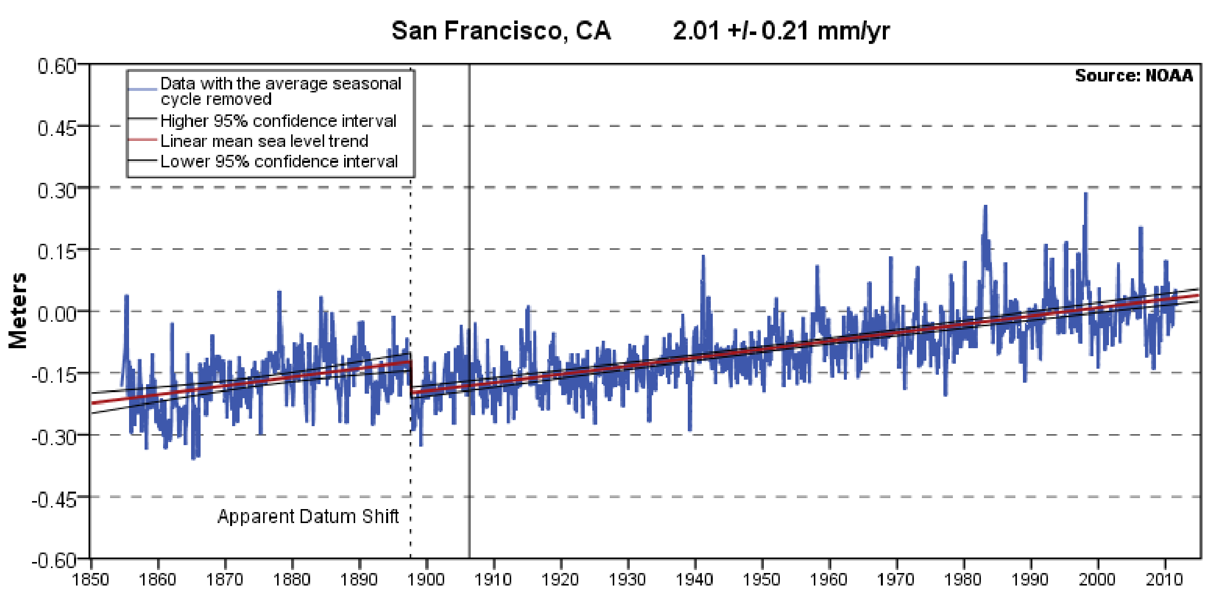

Figure 7-1. Sea Level Trend at San Francisco (NOAA, 2009)

The red line shows the mean sea level trend of 0.08 in/yr (2.01 mm/yr), and the black lines are the 95 percent confidence intervals. The solid vertical line is the 1906 earthquake, while the dashed vertical line is an apparent datum shift. Based on the historical data observed at San Francisco and following the guidance in EC-1165-2-211 of using the historical trend, a sea level rise of 0.08 in/yr (2.01 mm/yr) was chosen for the low case. This sea level rise value resulted in a 50-year increase of 0.33 ft (0.10 m) and a 100-year increase of 0.66 ft (0.20 m) at this location.

7.3.2 Intermediate Sea Level Rise

The intermediate sea level rise case was calculated using the modified NRC Curve I, as described in EC 1165-2-211. The equation used was

$$E(t_2) - E(t_1) = 0.07(t_2 - t_1) + b(t_2{}^2 - t_1{}^2)$$

where t_2 is the time between the projected time and 1986, t_1 is the time between current time and 1986, and b is a constant value of 7.74E-5 (2.36E-5 for metric) for the medium sea level rise. To estimate the sea level rise in 2061, 50 years from 2011, values of 75 and 25 were used for t_2 and t_1, respectively. For the 100 year scenario, values of 125 and 25 were used for t_2 and t_1, respectively.

Using the above equation, sea level rise values of 0.66 ft (0.20 m) and 1.71 ft (0.52 m) was calculated for the 50 and 100 year scenarios, respectively.

7.3.3 High Sea Level Rise

The high sea level rise case was calculated using the modified NRC Curve III as described in EC 1165-2-211. The equation is the same as given above, with a b of 3.30E-4 (1.005E-4 for metric). Again, for the 50 year scenario, 75 and 25 were used for t_2 and t_1, respectively, and for the 100 year scenario, 125 and 25 were used for t_2 and t_1, respectively.

Using the above values, a sea level rise of 1.94 ft (0.59) m was calculated for 50 years, and 5.51 ft (1.7 m) for 100 years.

7.3.4 Summary of Sea Level Rise Values

The sea level rise values calculated above were checked against other sources to determine their validity. Table 7-4 presents a summary of the calculated sea level rise values, and Table 7-5 presents a sample of the range of sea level rise values described in the literature.

Table 7-4. Summary of Calculated Sea Level Rise Values at San Francisco Gage 94114290

Sea Level Rise Scenario	50-Year Rise (ft)	100-Year Rise (ft)
Low	0.33	0.66
Intermediate	0.66	1.71
High	1.94	5.51

Table 7-5. Sea Level Rise Values Seen in Literature

Source	100-Year Sea Level Rise Range (ft)
California Climate Change Center – Projecting Future Sea Level Rise (CCCC, 2006)	0.43–2.92
International Panel on Climate Change – Synthesis Report (IPCC, 2007)	0.59–1.94
Delta Risk Management Strategy (DRMS) – Climate Change (DRMS, 2008)	0.66–4.59

As shown in the above tables, the 100-year range calculated from EC 1165-2-211 of 0.66 – 5.51 ft (0.2–1.7 m) compares well with the ranges presented in the literature.

The low sea level rise rate was verified with observed data at the San Francisco station. For 2001, the arithmetic mean of the hourly water surface elevations was 9.02 ft (2.75 m) NAVD88. After applying the 0.08 in/yr (2.01 mm/yr) sea level rise, an average of 9.02 ft (2.77 m) was predicted. This matched well with the observed average in 2010 of 9.09 ft (2.78 m).

7.3.5 Sensitivity of Hydraulic Model Results

The estimates in sea level rise described previously were used in a sensitivity analysis to evaluate the impacts of sea level rise on the water surface profiles in the American River Common Features project area. More information can be found in the Downstream Boundary Sensitivity Analysis Memorandum for File (USACE, January 2010b). The analysis focused on the downstream boundary conditions. The sensitivity of the downstream boundaries for the American River Common Features project was tested by varying downstream stage hydrographs at three locations to reflect increases in stage due to sea level rise. Water surface profiles from the original model and the sensitivity runs (with shifted downstream boundary stage hydrographs) were compared along the American River reach and Sacramento River reach.

The effects of shifting the downstream hydrograph to account for changes in stage due to sea level rise resulted in no changes on the Sacramento at Verona and minimal changes on the Sacramento at Freeport. The largest difference in stage was two-tenths of a foot for the10% (1/10) ACE event on the Sacramento River at Verona, and the average difference in stage was one-hundredth of a foot or less for the 1% (1/100) ACE event along the Sacramento River. There were also minimal variations in surface water elevations in the Yolo Bypass, indicating no significant change in the routing of the flood event through the combined waterways of the Sacramento River and the Yolo Bypass. These minimal changes in water surface elevations within the project area indicate that the project water surface profiles are dominated by riverine conditions and are not sensitive to reasonably estimated future sea level rise conditions.

7.4 Interior Drainage

An analysis was done to examine the interior drainage of the smaller, non-leveed streams in the three project basins (USACE November 2012). Measures to reduce the risk for flooding from these small streams are not being considered for alternatives, but the risk of flooding is being accounted for in the economic analysis. The results (flood depths and water surface elevations for the 10% (1/10), 4% (1/25), 1% (1/100), and 0.2% (1/500) ACE events will be used to estimate residual damages in the floodplain when doing the larger-scale risk estimation for the ARCF study. Plate 58 shows the project area for the interior drainage study.

Existing FEMA Digital Flood Insurance Rate Maps (DFIRMs) and associated flood insurance studies (FIS) were used to represent the interior flooding within the three basins. This analysis is general and approximate in nature and the level of detail is deemed appropriate in light of applying SMART Planning to this study. More information on the interior drainage analysis and process performed can be found in Interior Drainage Technical Memorandum (USACE November 2012).

Flood depths were determined for each recurrence interval by rasterizing the topographic data, the DFIRM shape files (30-foot grid cells), and the FIS data points in GIS and determining the difference between the two. The floodplains were created by interpolating the resultant rasterized flood depths. Plates 59-61 show the floodplains for the three areas.

The results indicate that the Interior drainage floodplains are significantly smaller than a floodplain from a levee break. The modifications to existing interior drainage facilities have been limited to bringing the facilities in compliance with Corps criteria for penetrations through levees (upgrading discharge lines, pumps, etc. to raise the drainage over the top of levee). An assessment of the capacity of existing facilities to address the residual flooding from interior runoff will be accomplished during the design phase or by the local maintaining agencies as part of their FEMA certification requirements.

7.5 Life Safety

Life safety information was taken from the USACE Levee Screening Tool (LST) for use in this study. The Levee Screening Tool supports the levee screening process by facilitating a preliminary assessment of the general condition and associated risks of levees in support of the USACE Levee Safety Program. (RMC, 2011)

The LST determines a screening risk index that considers routine inspection results and ratings coupled with a review and evaluation of historical performance data, as-built drawings, economic and life loss consequences, historic and current hydraulic and hydrology data, and other data. This helps determine the potential for failure and the consequences of failure. The culmination of the LST process is a screening risk index and risk classification that can be weighed against other screened levee segments in the portfolio.

Life safety can be evaluated using the consequence portion of the Levee Screening Tool (LST). Readily available data and information are used along with limited analysis to assess the potential consequences related to two different flooding scenarios: overtopping of a levee segment (with or without breach) and breach prior to overtopping of a levee segment. Consequence estimates focus on loss of life, but also include population at risk, number of structures, and direct monetary damage estimates to structures. The following is a description of the consequence results:

- **Population at Risk (Day/Night)**. These values represent the computed total number of people that would get wet if they did not evacuate when a levee breach occurred and inundated the entire leveed area up to the maximum profile elevation of the levee segment being screened.

- **Exposure Weighted Life Loss Estimates**. Computed "average" life loss estimates for each scenario that represent the loss of life caused by breach of the levee based on the movement of people in and out of the leveed area throughout the day.

The life safety and life loss estimates can be found in Table 7-6. This information comes from a series of Levee Screen Tool Presentations by the Sacramento District on the three basins or systems. (USACE, 2011), (USACE, 2012a), (USACE 2012b)

Table 7-6. Life Safety and Life Loss Information
From USACE's Levee Screening Tool

American River North		Natomas	
Population at Risk (Day)	58,558	Population at Risk (Day)	76,973
Population at Risk (Night)	51,380	Population at Risk (Night)	65,696
Loss of Life (Day)	170	Loss of Life (Day)	669
Loss of Life (Night)	156	Loss of Life (Night)	553
American River North, Small Streams		**American River South**	
Population at Risk (Day)	15,457	Population at Risk (Day)	350,000
Population at Risk (Night)	23,816	Population at Risk (Night)	439,491
Loss of Life (Day)	77	Loss of Life (Day)	503
Loss of Life (Night)	131	Loss of Life (Night)	978

8 EROSION

8.1 Overview and Assumptions

Erosion is the removal of sediment, rocks, cobble, vegetation and general deterioration of a bank or a levee due to the power of water, often measured by shear stress and velocity. The probability of erosion eroding a levee resulting in failure can present a significant flood risk. There have been many studies on erosion, sediment transport, and channel stability and in the study area, with most of the focus on the American River.

The primary concern about erosion related flood risk in the project area is on the American River and secondary concern is on the Sacramento River. While there may be erosion occurring on the smaller tributaries in the project area, it is assumed that any repairs would be incorporated into current designs with limited added costs, would not involve large quantities of rock, and would not have specific designs called out.

The plan for erosion management features is ongoing; more analysis is expected to provide greater insight. Erosion repairs are expected to be part of all three alternatives and refinement efforts will continue beyond the Tentatively Selected Plan (TSP) milestone. Existing erosion conditions in the project area are presented briefly in the following section. A separate multidisciplinary Erosion Protection Report was developed for this study that contains addition information.

8.2 Existing Bank Erosion Conditions

Below is a brief description of the existing bank erosion condition for each of the reaches in the project area. This section is based on existing annual erosion survey reports from the Sacramento River Bank Protection Project that covers the entire Sacramento River Flood Control System. (USACE 2012a) See Plate 3.

Sacramento River – Middle Reach, Colusa to Sacramento (RM 79 to RM 61). The middle reach of the Sacramento River has the levees close to the river and multiple diversion structures to move flow into the bypass system. The Sacramento River was split at the confluence with the American River for the purposes of this discussion because the conditions of the river change at this location. The middle reach was intentionally designed with the levees close to the banks to help move some of the bed load and debris that remained from the days of hydraulic mining. In addition, USACE was responsible for keeping the river navigable up to the city of Colusa. As a result of this design, much of the reach is protected with rock, especially the outsides of bends. The majority of the rock in this reach is cobbles placed prior to the 1960s and some areas with more recent quarry stone. The cobble sites are reaching the end of their design life. Figure 8-2 shows a typical view of the middle reach of the Sacramento River.

Figure 8-1. Typical View of the Middle Reach of the Sacramento River

Sacramento River – Delta Section (RM 61 to RM 45). The Delta reach of the Sacramento River has levees placed directly adjacent to the main channel and is tidally influenced. The location of the channel has been relatively stable for the past 150 years. A large percentage of this reach has already been armored with riprap. This area has heavy wave action from recreational boats and wind, and the banks are heavily used by the public. Many of the levees are constructed of dredged soils from the bottom of the channel. Figure 8-3 shows a typical view of the Delta section of the Sacramento River. The causes of erosion in this reach are boat wake, wind-wave, mass failure, fluvial processes, and public use.

Figure 8-2. Typical View of the Delta Section of the Sacramento River

American River. The American River reach is located downstream of Folsom Dam, is therefore generally sediment-starved, and has been eroding and transporting the fine materials from the channel bed. Once the fines have been removed and the bed is armored, the channel is expected to move laterally and erode the banks. The right bank levee is set back from the channel for the lower 5 miles. Boat wake is not a concern as there is a no wake zone for the entire river. The main causes of erosion are fluvial, tree undercutting, and public use. This river is generally well maintained and has had many bank repairs in the recent years. Figure 8-4 shows a typical view of the American River.

Figure 8-3. Typical View of the American River

Natomas East Main Drainage Canal, Arcade Creek, and Dry Creek. Arcade Creek and Dry Creek (formerly known as Linda Creek, and now more commonly referred to as Big Dry Creek) drain water from the Rio Linda, Roseville, Antelope, Citrus Heights, and Carmichael areas. Arcade Creek has the levees relatively close to the channel; however, the small amount of floodplain maintains a healthy riparian habitat. Dry Creek has a large floodplain but relatively little riparian habitat, as the floodplains appear to be used for cattle grazing. Figure 8-5 shows a typical view of Dry Creek. The Natomas East Main Drainage Canal (NEMDC) directs the flow from Arcade and Dry creeks and sends it south to the American River. NEMDC is a man-made channel that runs north-south and protects the east side of Natomas.

Erosion is not considered to be a significant problem on these smaller tributaries or on the Natomas Cross Canal, Pleasant Grove Canal, or Coon Creek Interceptor (described below). Any work needed to address erosion will be part of the levee design effort and were accounted for in the cost contingency and is not expected to add any cost or change the hydraulics of these reaches.

Figure 8-4. Typical View of Dry (Linda) Creek

Natomas Cross Canal, Pleasant Grove Canal, and Coon Creek Interceptor. Pleasant Grove Canal and Coon Creek Interceptor collect water from the east foothills and communities of Lincoln and Pleasant Grove. These flows are then directed into the Natomas Cross Canal, which moves the water down to the Sacramento River. Pleasant Grove Canal and Coon Creek only have levees on the east side. The levees are steep with some grass and shrub vegetation. The Natomas Cross Canal is man-made and the levee on the south side was recently rebuilt. The south levee is mowed and grazed by sheep in the summer while the north levee has tall grasses with shrubs/trees on the lower bank. Figure 8-6 shows a typical view of the Natomas Cross Canal.

Figure 8-5. Typical View of the Natomas Cross Canal

8.3 Existing Sediment Transport

A sedimentation analysis was not completed for this study. However, a sediment study of the Sacramento River from Colusa to Freeport is near completion under the Sacramento River Bank Protection Project (NHC, 2012). The main objective of this sediment study was to investigate sediment transport processes and geomorphic trends along the lower Sacramento River and its major tributaries and distributaries. A HEC-6T sediment transport model was developed for the study reaches of the Sacramento, Feather, and American Rivers to estimate degradational or aggradational trends over the next 50 and 100 years.

For the entire study reach of the Sacramento River (RM 79-46), the average bed elevation decreases by 0.02 ft for the 50-year simulation period and decreases by 0.10 ft for the 100-year simulation period. Despite a few significant (on the order of feet) localized vertical adjustments in the channel geometry (mostly associated with infilling of deep pools and scour of elevated riffles), the study reach of the Sacramento River appears to be generally stable, with a slight degradational trend.

On the lower American River, the long-term simulation results indicate that most of the 22-mile long study reach is actively degrading. Upstream sediment supply on the American River is interrupted by Folsom and Nimbus Dams, which results in “sediment-hungry” waters and channel degradation below the dams. Simulated long-term changes in the American River bed profile range from 9-16 ft of degradation to about 3-4 ft of aggradation. Degradation is simulated upstream of RM 12 and downstream of RM 11, while aggradation is simulated in a short reach between RMs 12-11. For the entire study reach of the American River, the average bed degradation is 4.8 ft and 5.8 ft for the 50- and 100-year simulations, respectively.

It should be noted that the channel of the American River is highly irregular at many locations (especially in braided reaches upstream of RM 8). These irregular reaches may not be adequately represented in the 1-d HEC-6T model. Therefore, results obtained for the irregular reaches may be subject to modeling errors and should be treated with caution. In general, however, the degradational trend predicted by the model agrees with stage-discharge records showing ongoing channel degradation of the American River channel.

8.4 Existing American River Channel Stability

Specific to the American River, multiple analyses have been completed and many are still underway to better understand the overall channel stability. These efforts are ongoing and are expected to be incorporated into the design of the tentatively selected plan.

Recognizing that significant efforts have been completed and that current studies are not yet finished, the hydraulic characteristics of the American River channel under with-project conditions were evaluated using existing information. The 2004 Ayres Report, “Lower American River – Erosion Susceptibility Analysis for Infrequent Flood Events” for the American River provided 2-D hydraulic model results of velocity, shear stress and water depth for flows of 115,000 cfs, 130,000 cfs, 145,000 cfs, and 160,000 cfs. The report and model results were provided to the Civil Design and Geotechnical Sections; additional information on erosion designs can be found in their respective appendices.

The conclusions from the Ayres 2004 report provide further evidence for the need of erosion protection measures to reduce the flood risk on both sides of the American River and are described below:

> *Based upon our modeling efforts, field review and overall experience with the Lower American River system, we offer the following conclusions:*
>
> 1. *Geomorphic principles, the thalweg profile, and the field review all agree that the river system is degradational under present operating conditions.*
>
> 2. *The Lower American River is starved of sediments by Folsom and Nimbus dams. Bedrock has been reached in the channel bottom as far downstream as Guy West Bridge, and this bedrock is slowing further degradation. With the river starved for sediments and without significant bed slope reduction, it will now tend to erode laterally to satisfy the need for sediment.*
>
> 3. *The hydraulic modeling shows areas of riverbank and levees where allowable velocities for vegetative cover and soil materials are exceeded. These sites need to be evaluated in more detail to determine if a levee failure is likely to occur.*
>
> 4. *The field review verified that erosion of the riverbank is occurring (RM 9.0R) even at low flow conditions of 7,000 cfs, which was the peak flow from the 2003 runoff season. Erosion on the American River is continually occurring. This condition is leaving the channel banks scarred and susceptible to further erosion, especially during a high flow event. In addition, this condition is further reducing the amount of berm separating the main channel from the levee. The loss of underlying vegetation is leaving bare soil, which is susceptible to erosion at a lower velocity.*

8.5 Existing Wind-wave

Wind-wave analysis was done to evaluate the risk of failure due to wind-wave erosion for about 85 miles of the American River Common Features levees in Sacramento and Sutter Counties for coincident 0.5% (1/200) ACE event water levels and extreme wind events (NHC, 2010). The study approach and methods followed Engineering Circular 1110-2-6067 and other technical publications related to wind-wave analysis. Wind-wave characteristics were calculated from the highest observed winds on record at stations in the Sacramento area. Frequency analysis of the annual maxima at the stations, by direction, suggested that the maximum 1-hour gusts had about a 2% (1/50) ACE event. No studies were performed to determine the coincident probability of the (1/200) ACE event water level and the maximum wind occurring simultaneously.

Each site was assigned a risk level based on the highest risk assigned for either levee face erosion or overtopping for any wind direction at a given site. The risk at each study site was than generalized to nearby sites, which were expected to experience similar wave heights and which had similar geometry and protection. Overall, 46 miles of levee were determined to be at high risk of failure due to wind-wave erosion during coincident extreme wind and water levels, 25 miles were determined to be of moderate risk, and 14 miles were assumed to be low risk. High risk sites are likely to require repair for the levee to be a certifiable flood defense structure. Sections of levee with moderate risk are not expected to require repair and any damage at these locations during a large flood should likely be mitigated with flood fighting. Low risk sites do not require repair and likely will not require any flood fighting for wind-wave erosion.

It should be noted that the possibility of levee breach due to wind-wave action is small compared to other issues currently being considered, such as underseepage and stability, and that conservative assumptions were made in regards to the need for erosion protection due to wind-wave action on the PGCC and the upper NEMDC.

8.6 Existing Boat Wave Erosion

Boat wave erosion has not been accounted for in this analysis because the impact of boat wave erosion in the project area is unlikely to be significant. Only smaller recreational boats operate in the Sacramento and lower American Rivers, and the other project reaches do not have enough consistent depth or width of channel to sustain boat traffic. Any repairs needed from boat waves is assumed to be addressed as part of standard operation and maintenance of the levees.

8.7 Existing Vegetation Analysis (Tree Scour)

The preliminary designs for erosion protection include leaving some of the vegetation in place, an option made possible by a waiver process included in ETL 1110-2-571. A pier scour analysis to represent tree scour (likely using HEC-18) is included in the application for waiver. This effort is considered part of the erosion analysis, and is expected to be done as part of the refinement during PED.

8.8 With-Project Erosion Features

With the levees set back on the American River, there are some additional options available to address erosion. A launchable rock trench at the levee toe is considered a viable measure, along with protecting the bank with a rock layer. All launchable rock trenches would be constructed outside of the natural river channel and designed to deploy once erosion has removed the bank material covering it.

In a flood event where the bank erodes back to the levee, the launchable rock would already be in place to protect the levee slope and nearby bank, halting the erosion. The rock trench can be covered with dirt and vegetation so that the entire fix is not visible. A key assumption for the rock trench is that it would not change the hydraulics, because the design would not affect the cross sectional area of the channel. See the geotechnical report for information on the details of this erosion repair measure.

The preliminary locations where bank protection (as opposed to rock trench protection) was proposed suggested a concern about channel capacity. An initial hydraulic model run was made with a revised geometry reflecting the obstruction estimated for the bank protection. This model run showed stage increases approximating 1 foot for the 0.5% (1/200) ACE event (currently set to be 160,000 cfs). Given the significant increase in stage, the option of replacing the bank protection upstream of the narrowest part of the American River (near Guy West Bridge, approximately RM 6.5) with rock trench measures was evaluated with another hydraulic model run. The results indicated that this limited erosion fix option caused very little change in stage for the 0.5% (1/200) ACE event.

Based on this analysis, the rock trench measure is proposed for areas upstream of the Guy West Bridge (approx. RM 6.5) with bank protection or a rock trench downstream of this point. Further refinement in PED will likely be necessary to verify this measure.

8.9 Bridge Scour

There are over 15 bridges crossing the channel on multiple reaches in the project area. Bridges along the Sacramento and American rivers will likely need an analysis during design to account for bridge scour protection. This effort is considered part of the erosion analysis and is expected to be done as part of the refinement during PED.

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LEGEND

- Rivers
- Sacramento Watershed
- Lakes and Reservoirs
- Designated Floodways

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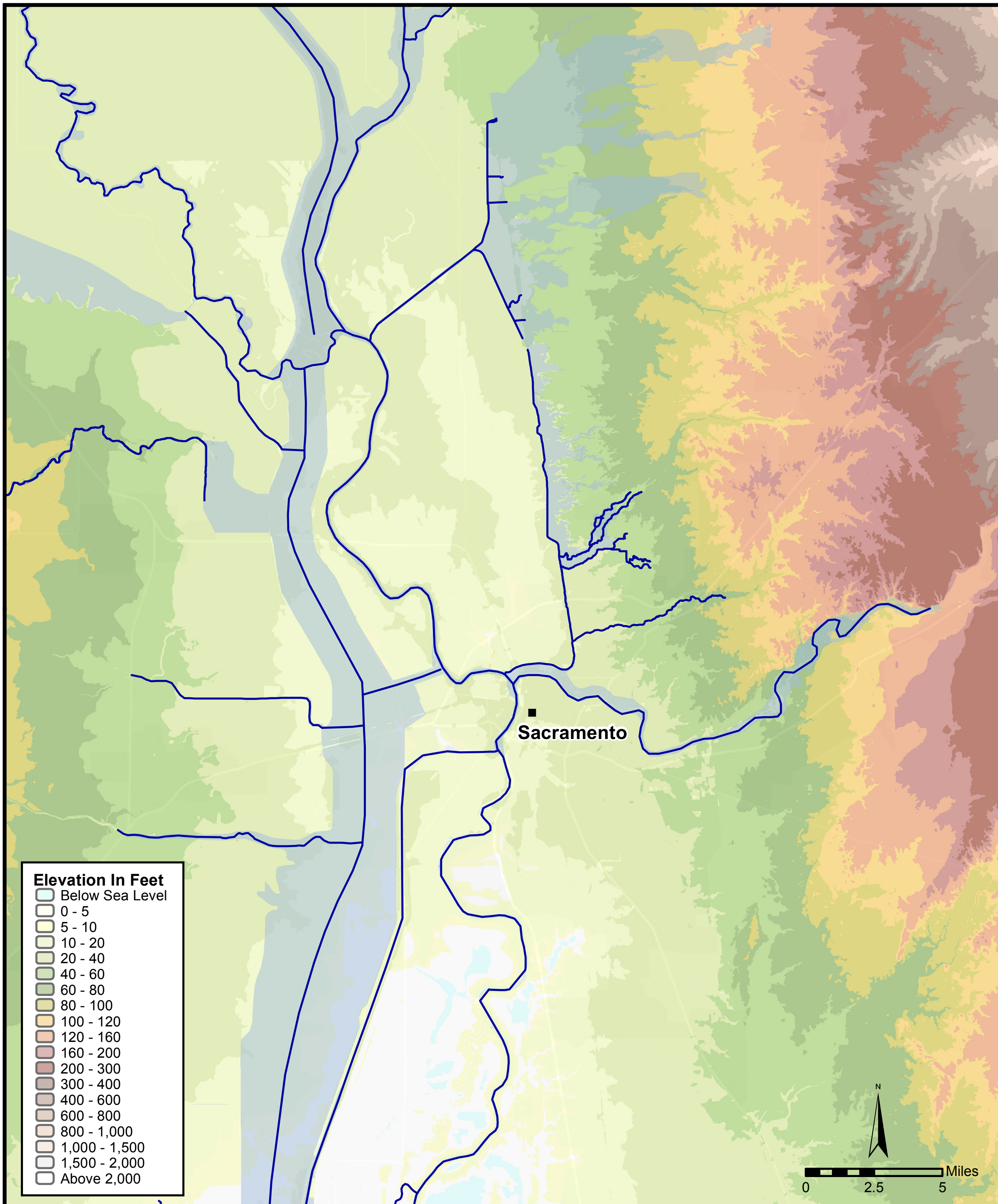
SACRAMENTO DISTRICT

Feb 2013



LEGEND

Rivers

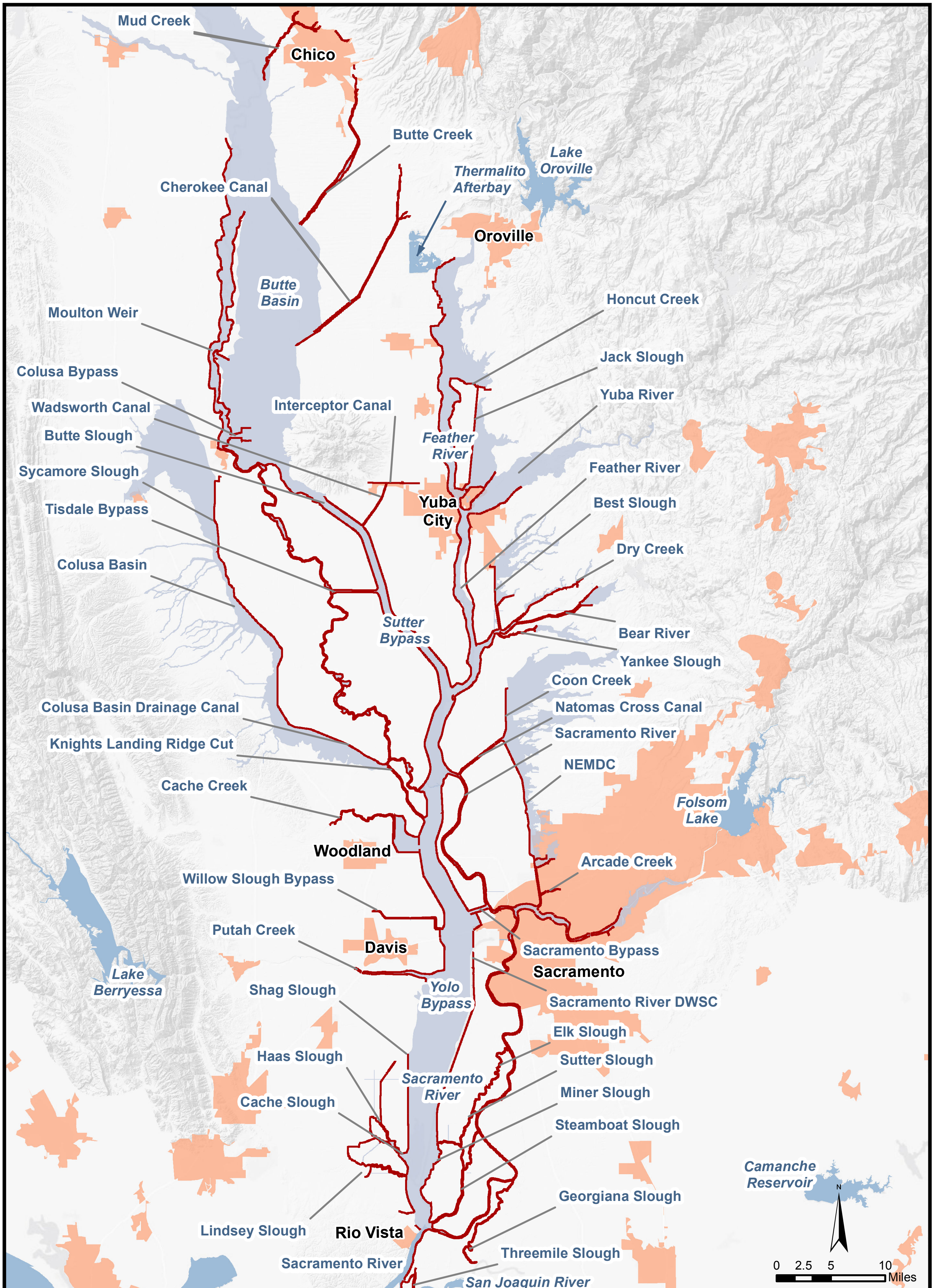
Floodways

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

GENERAL TOPOGRAPHIC MAP

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

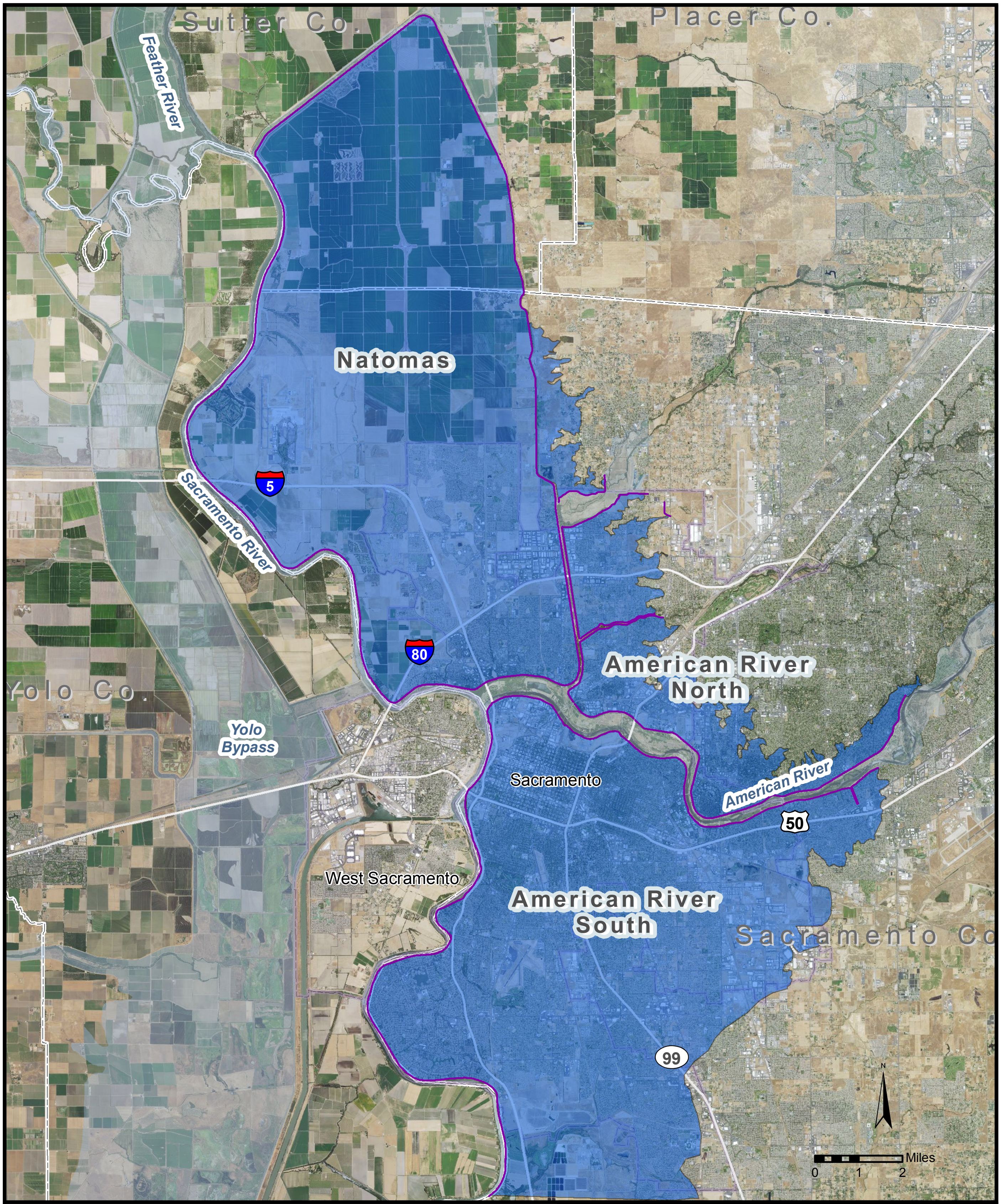
Feb 2013



AMERICAN RIVER COMMON FEATURES GRR SACRAMENTO, CALIFORNIA	Sacramento River Flood Control System	U.S. ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

Feb 2013

Plate 3



LEGEND

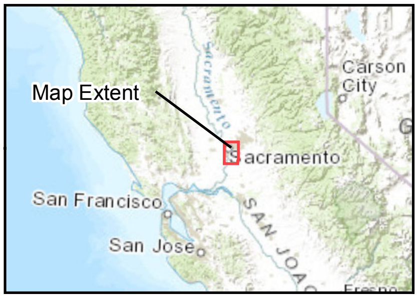
ARCF Levees

ARCF Project Area

Floodways

Cities

County Lines

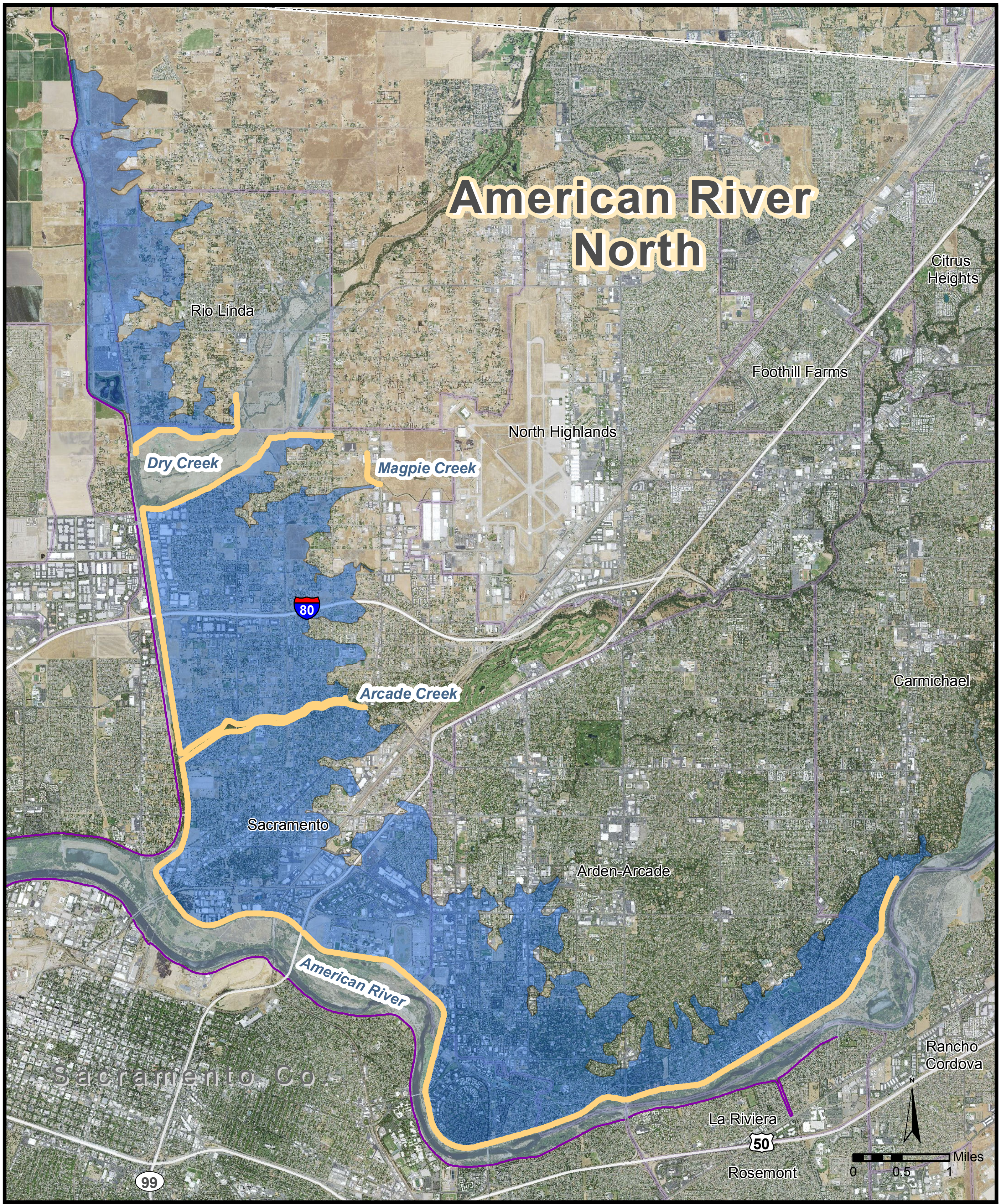


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

PROJECT AREA MAP

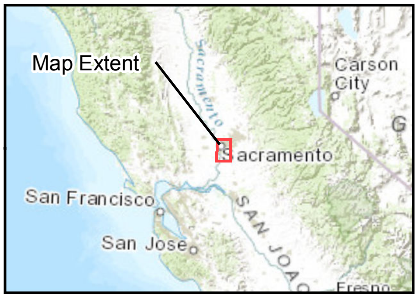
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015



LEGEND

- ARN Project Area
- ARN Levees
- ARCF Levees
- Floodways
- County Lines
- Cities

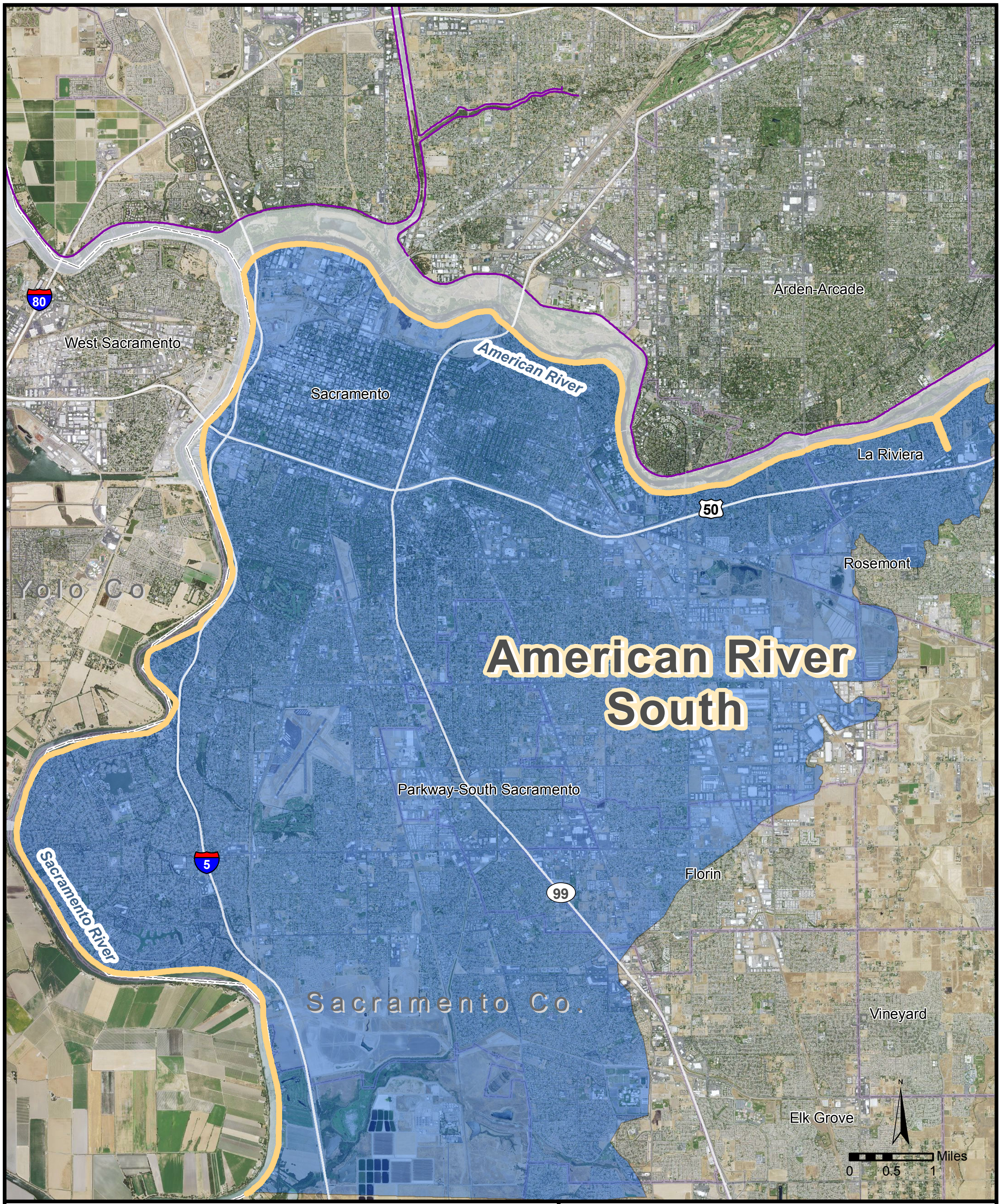


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH PROJECT AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015



LEGEND

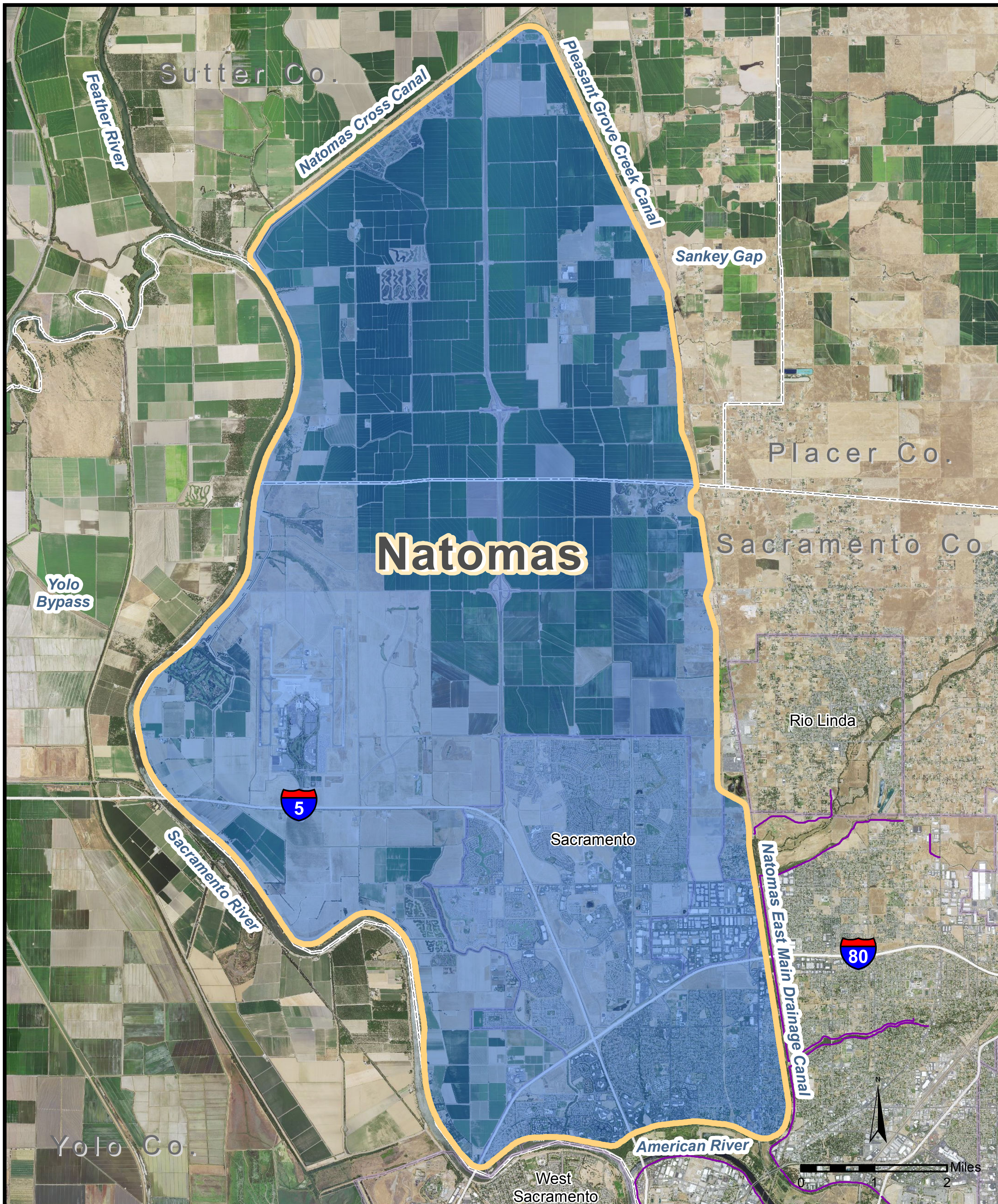
- ARCF Levees
- ARS Levees
- County Lines
- Cities

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER SOUTH PROJECT AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015



LEGEND

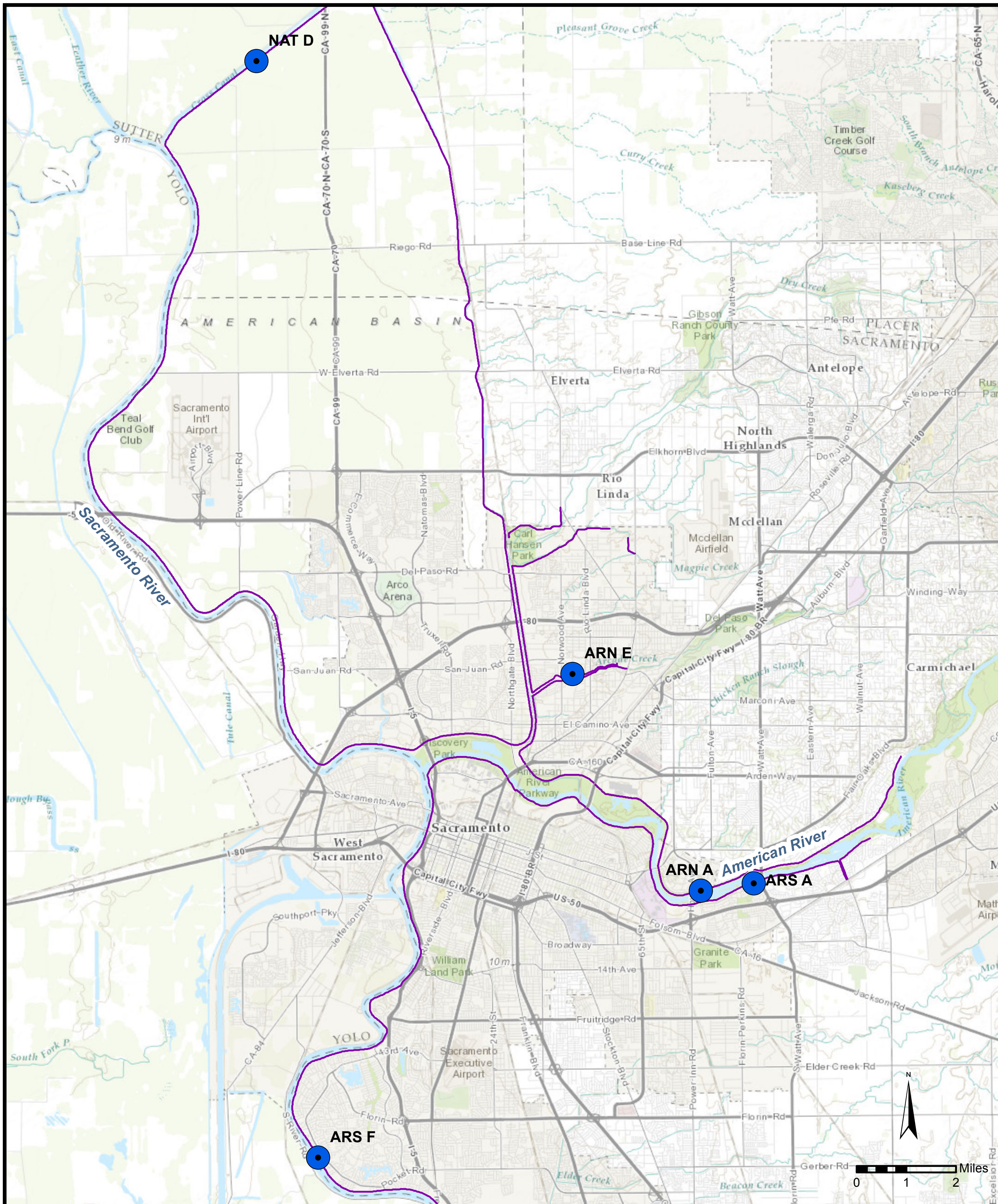
- ARCF Levees
- Natomas Levees
- Cities
- County Lines

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS BASIN PROJECT AREA

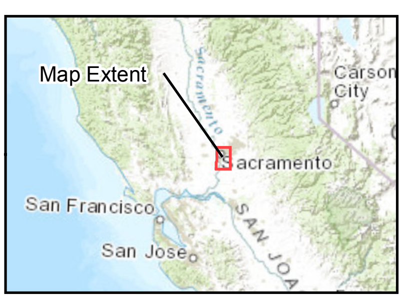
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015



LEGEND

- ARCF Index Points
- ARCF Levees

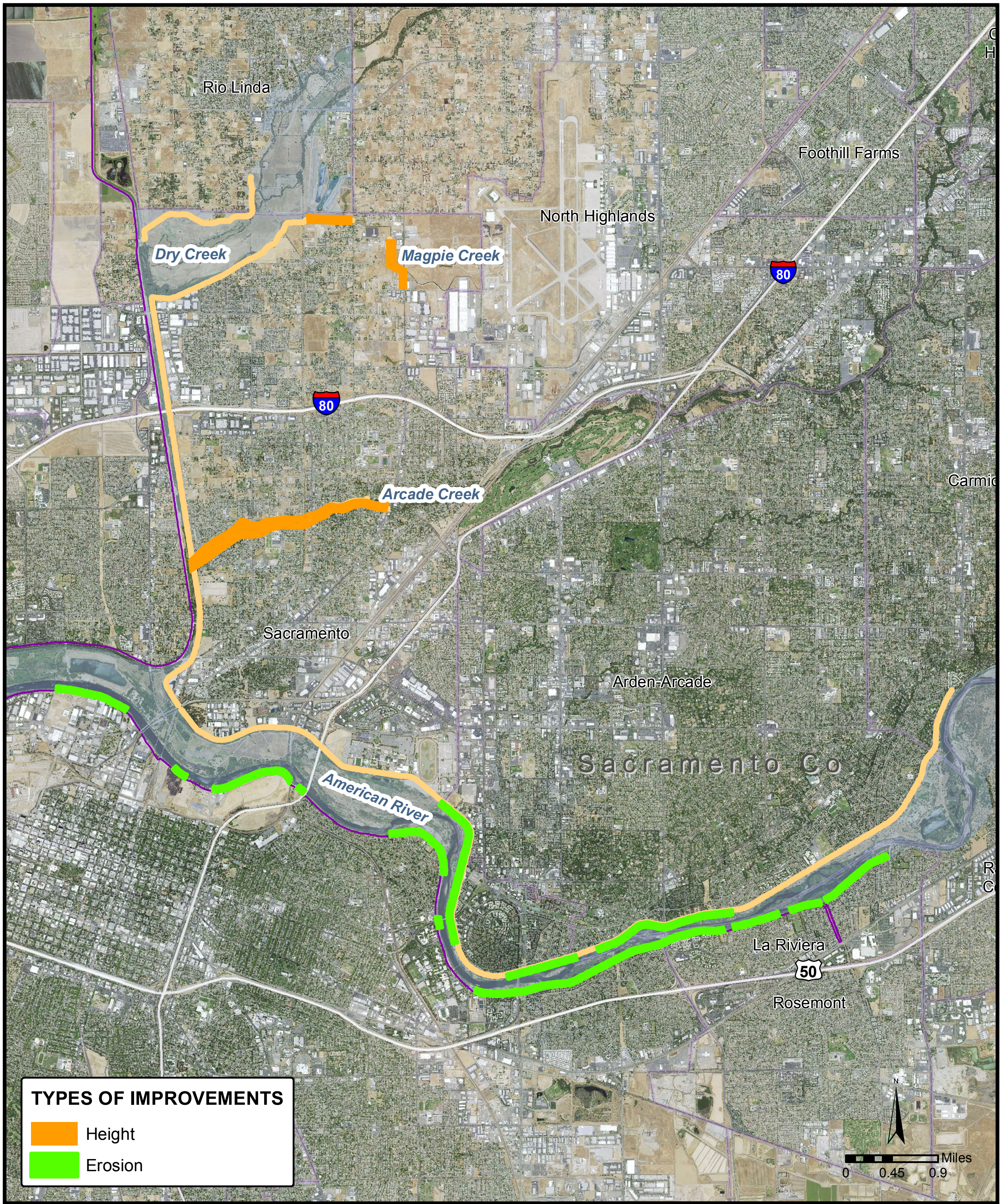


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

INDEX POINT LOCATION MAP

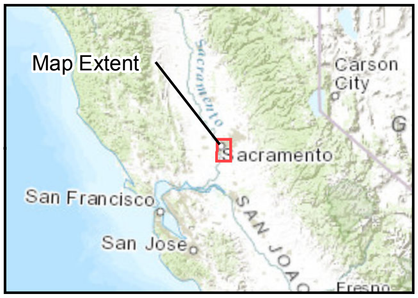
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015



LEGEND

- ARN Levees
- ARCF Levees
- Floodways
- County Lines
- Cities

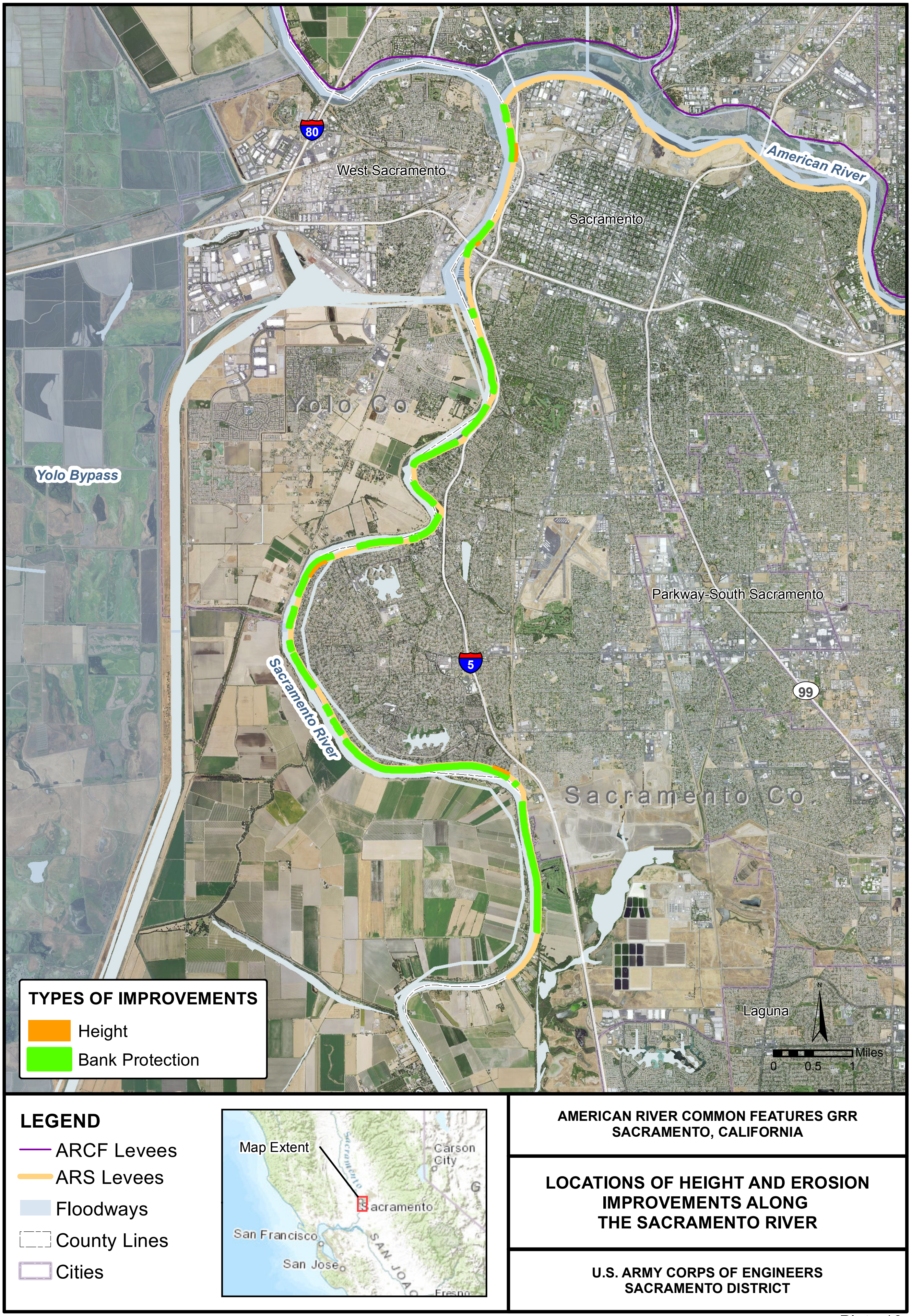


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

LOCATIONS OF HEIGHT AND EROSION IMPROVEMENTS ALONG THE AMERICAN RIVER AND EAST SIDE TRIBUTARIES

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Aug 2015

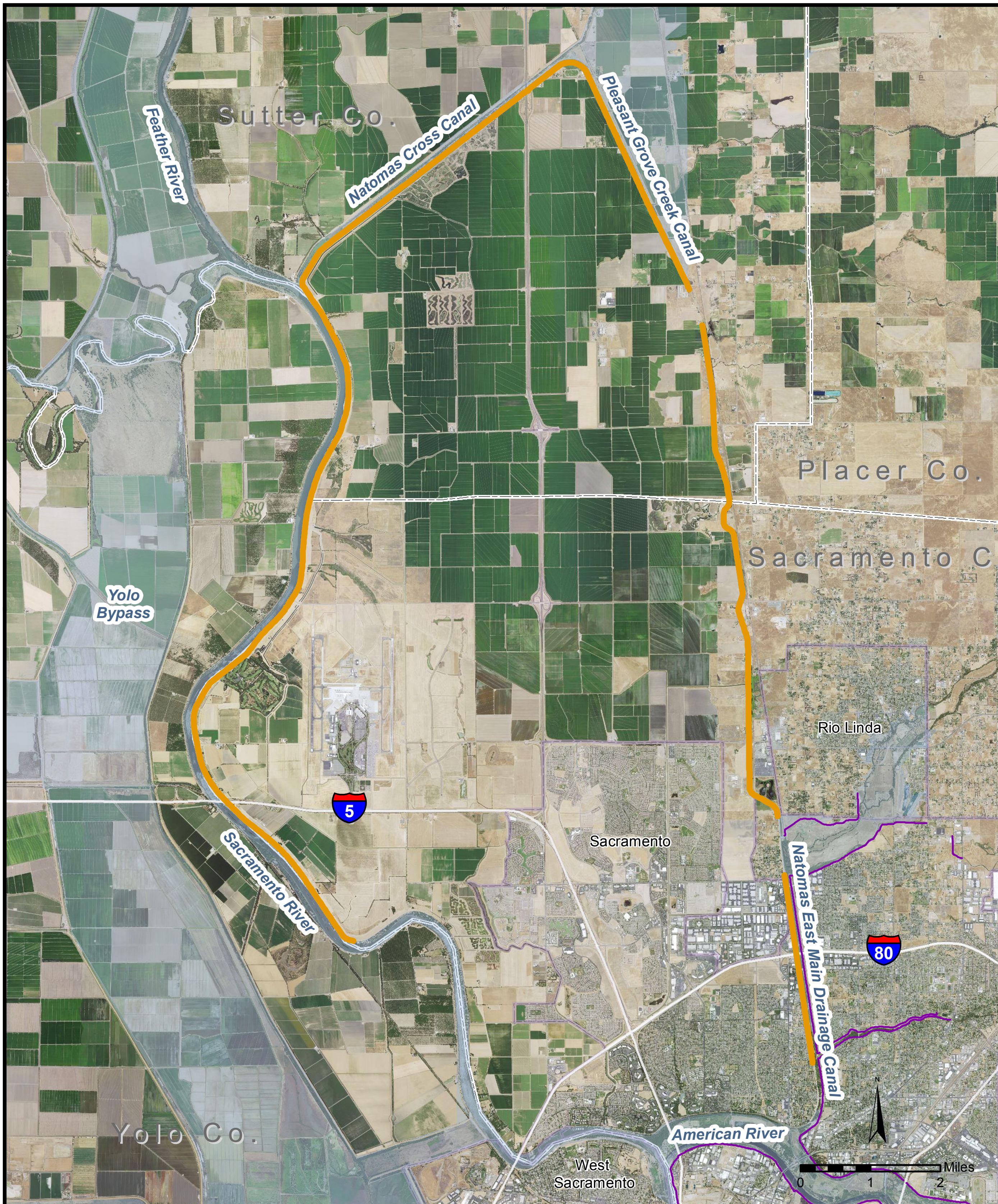


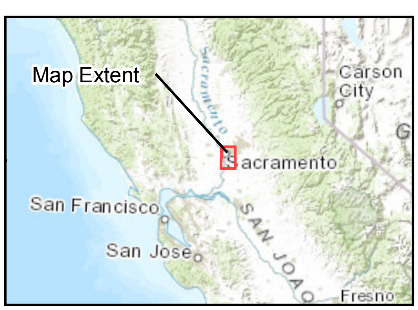
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

LOCATIONS OF HEIGHT AND EROSION IMPROVEMENTS ALONG THE SACRAMENTO RIVER

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Sept 2015





LEGEND

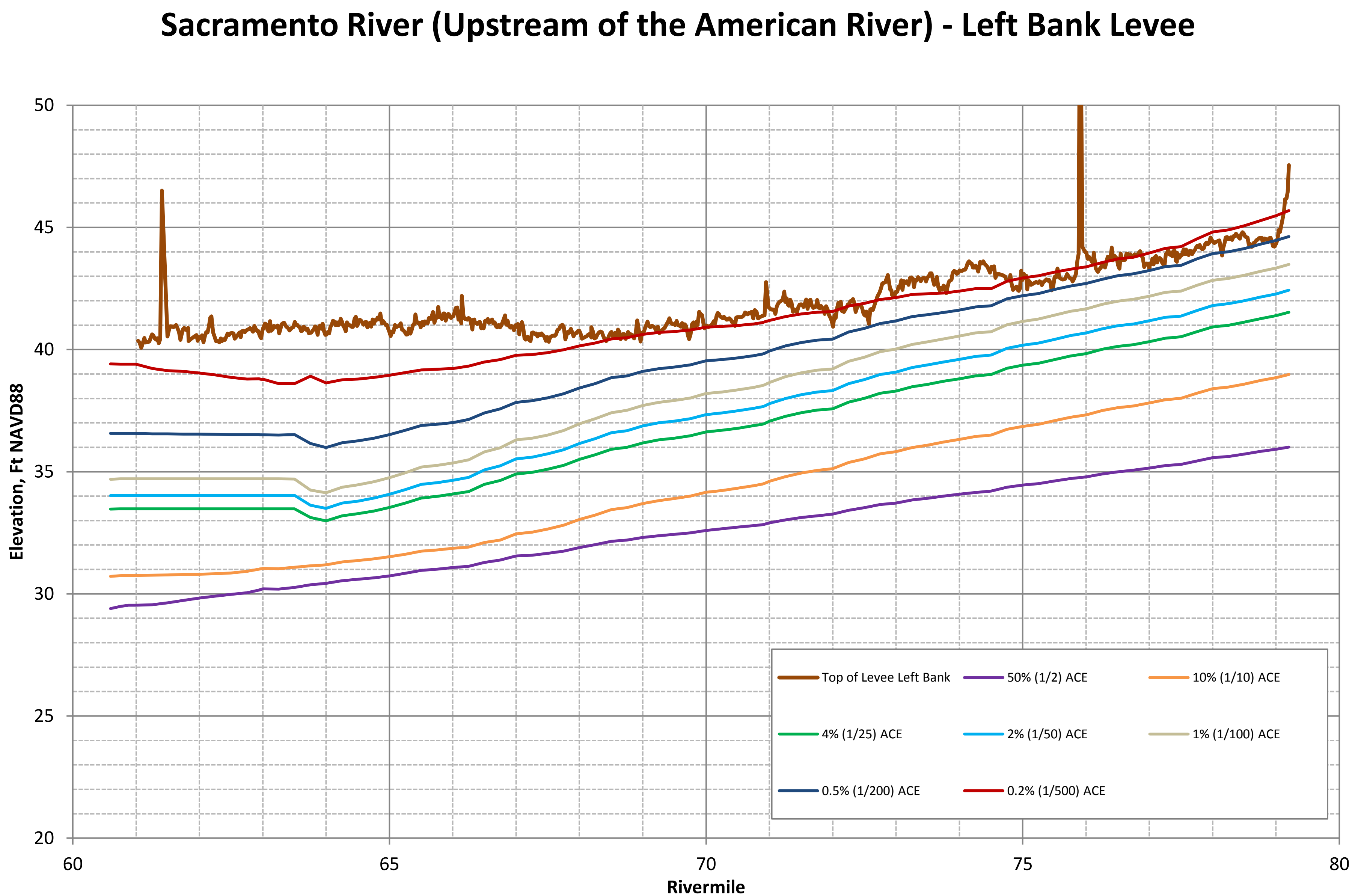
- Height
- ARCF Levees
- Floodways
- Cities
- County Lines

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

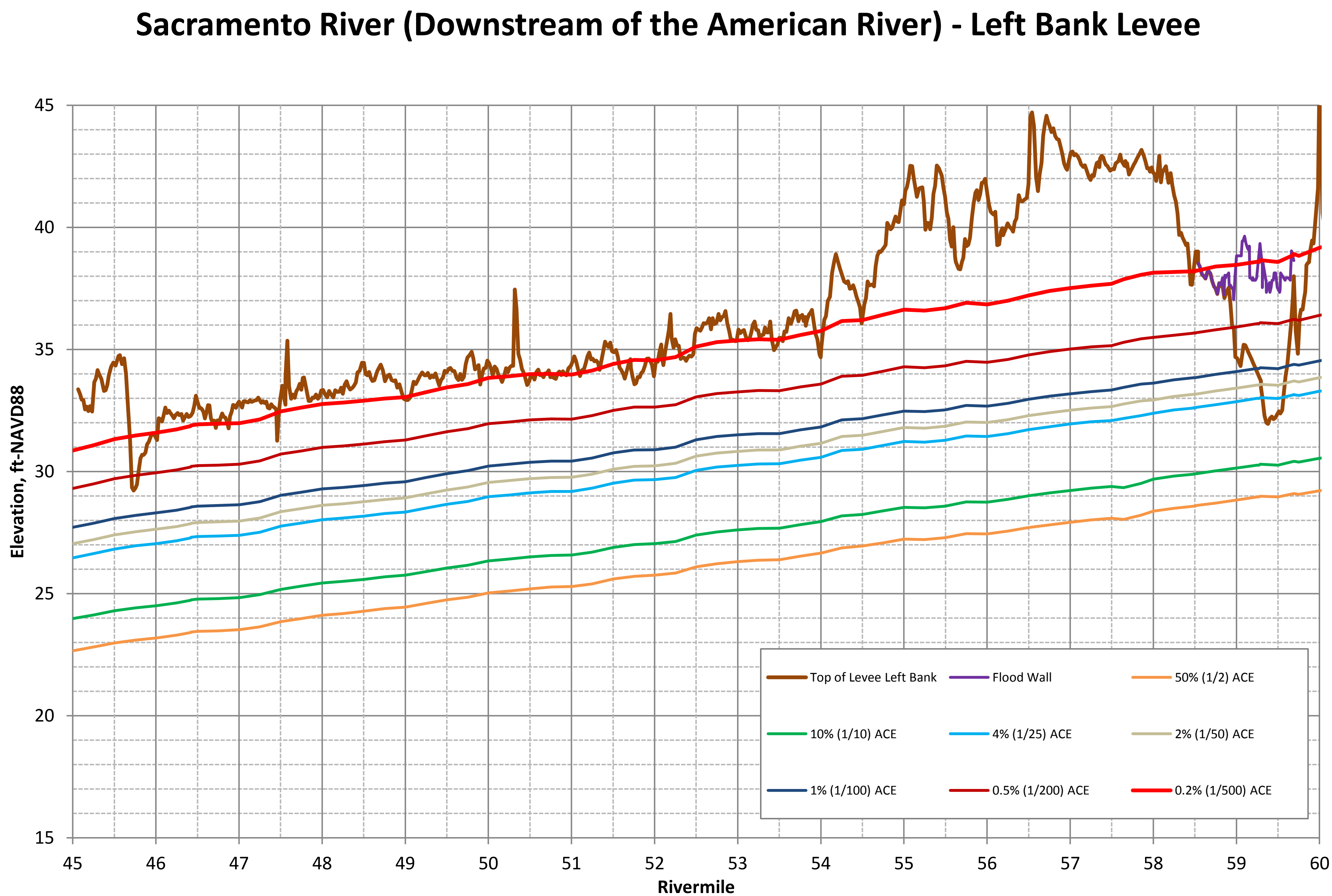
LOCATIONS OF HEIGHT IMPROVEMENTS ALONG THE NATOMAS BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

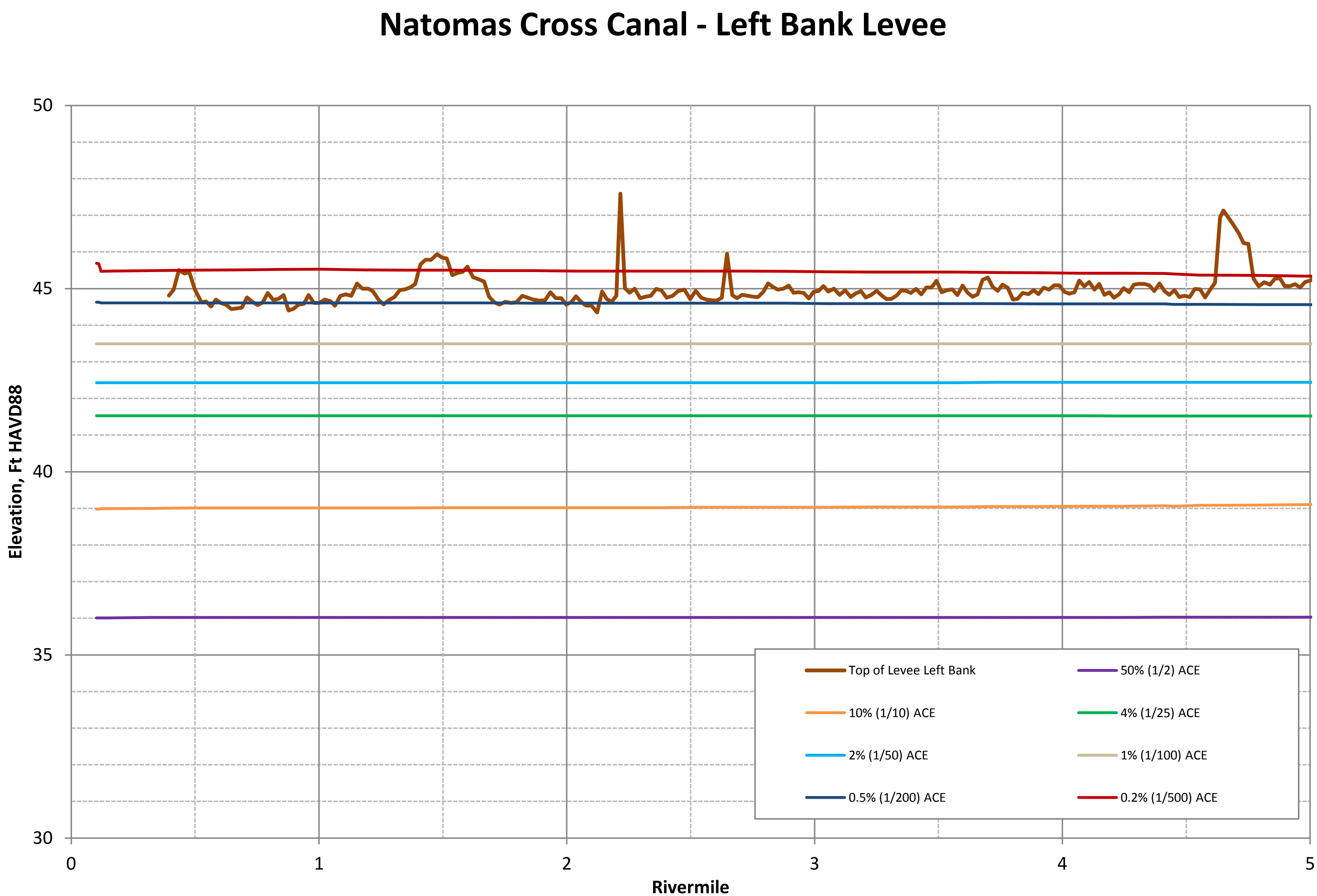
Sept 2015



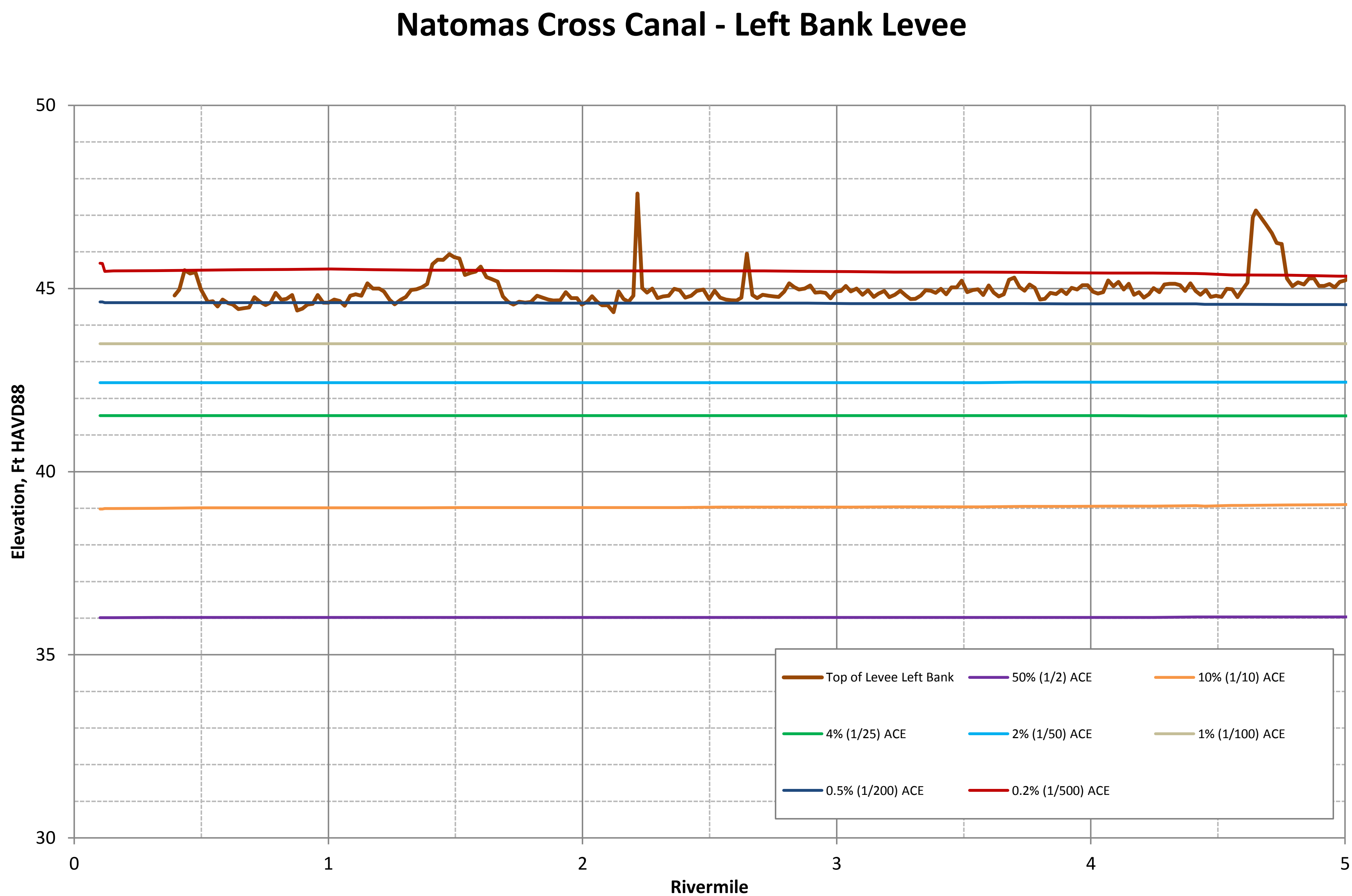
American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



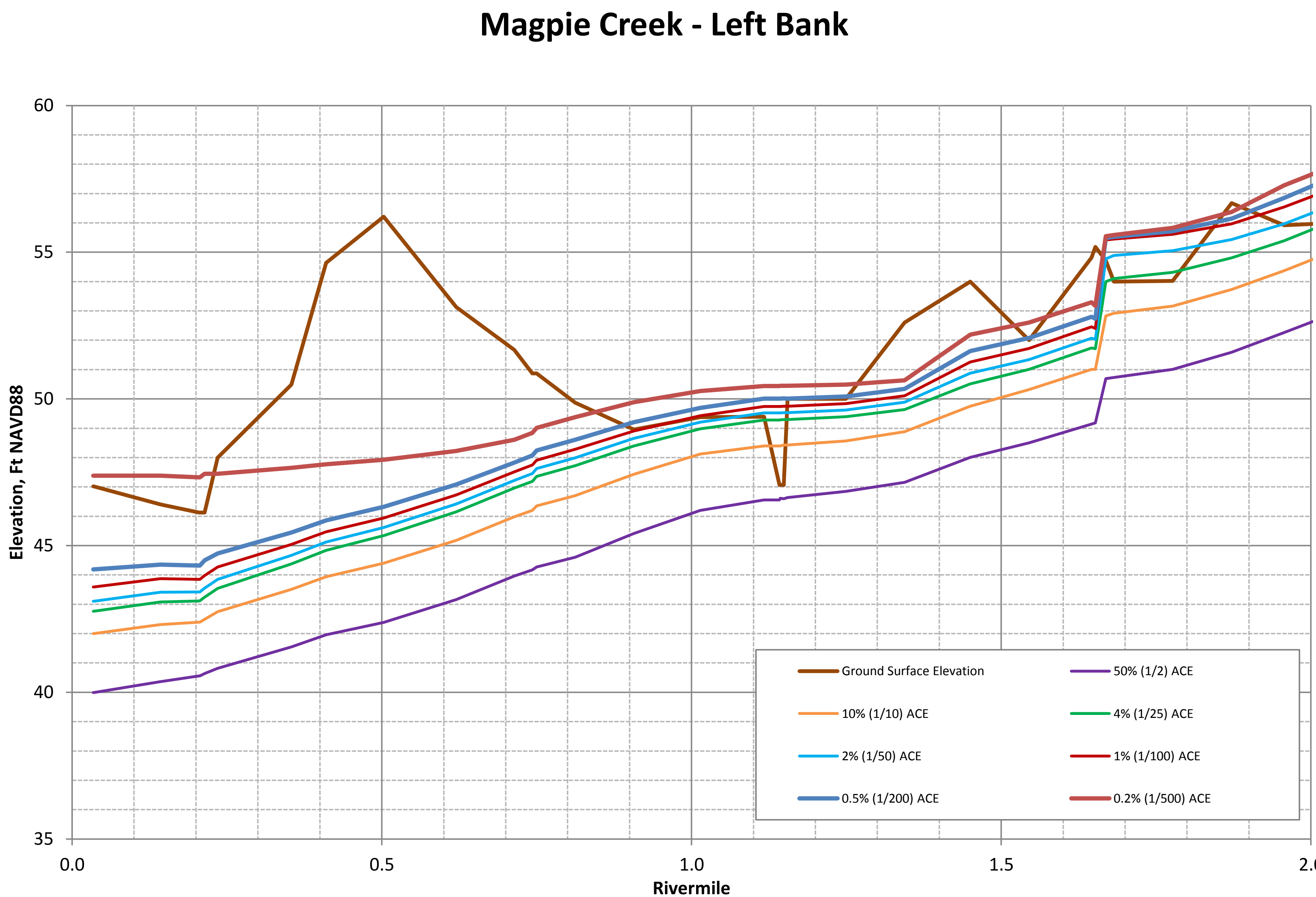
American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



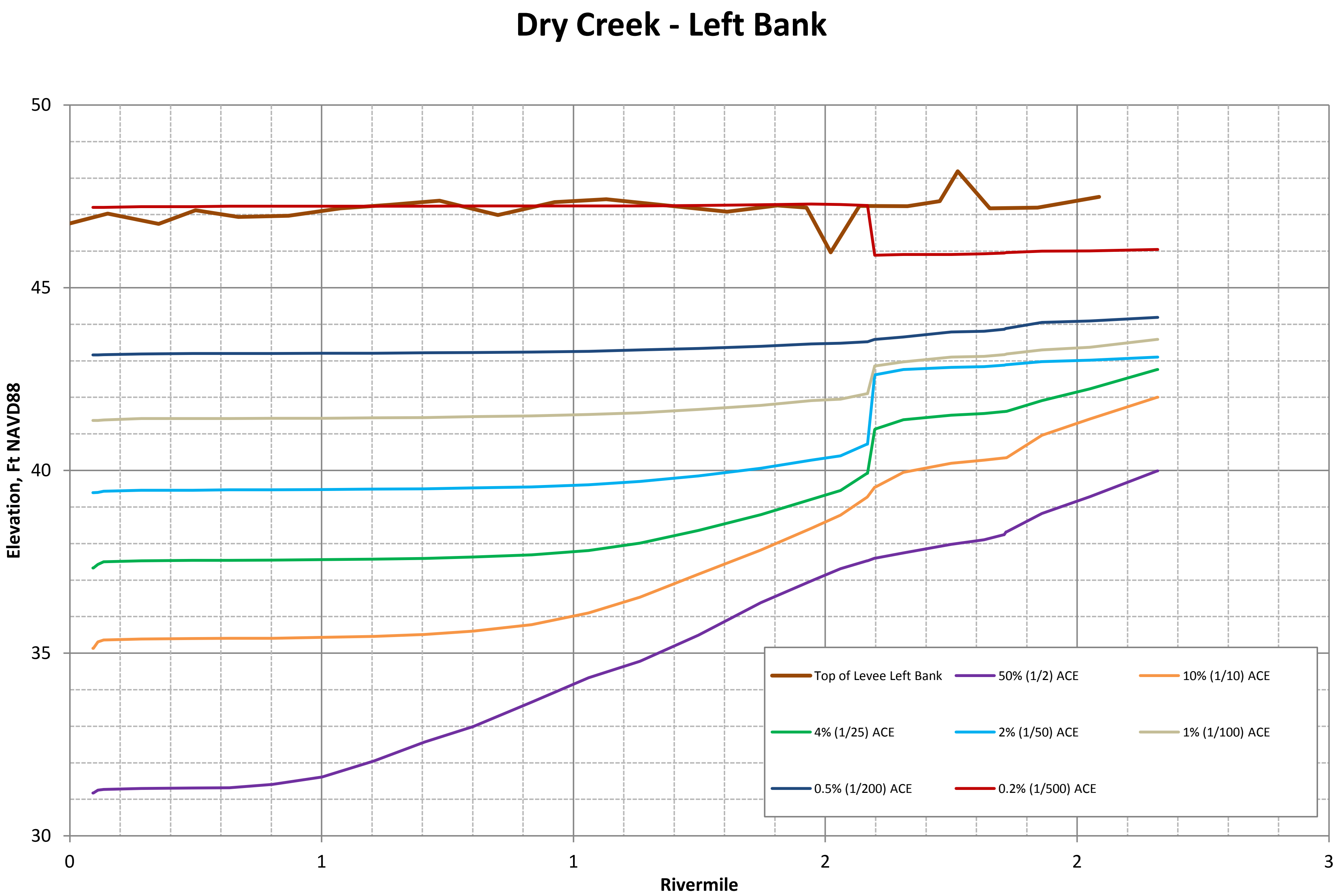
American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



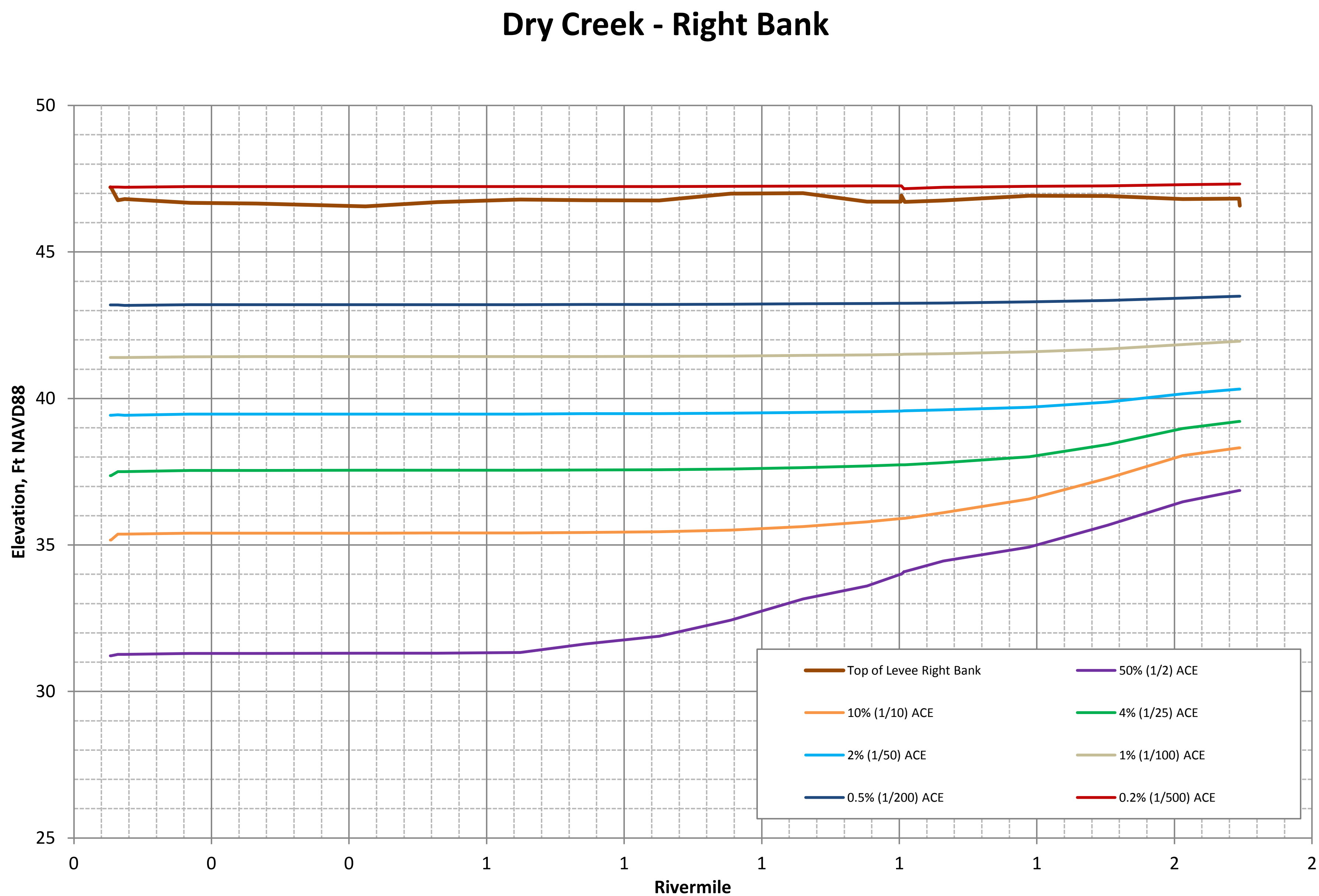
American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



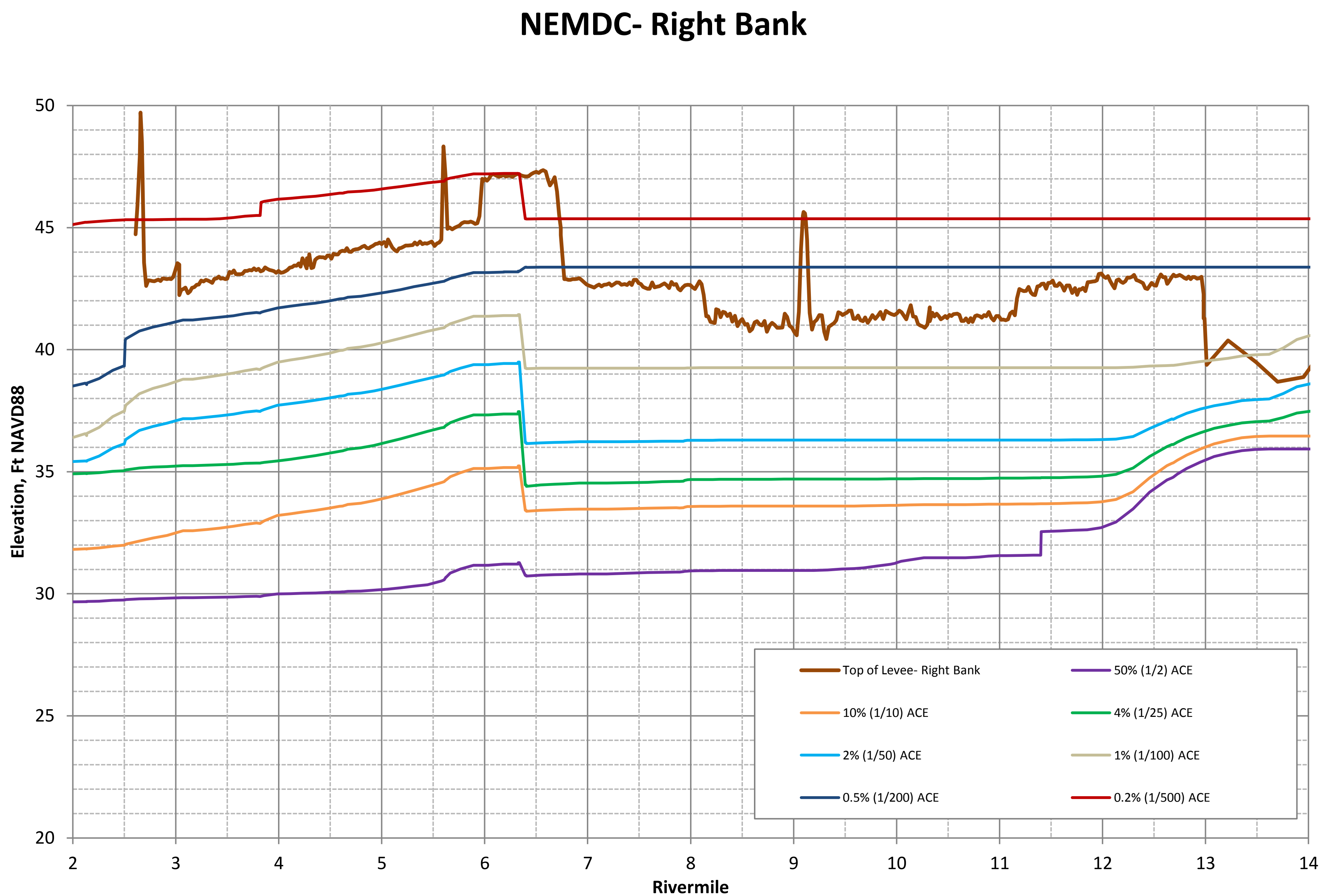
American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District

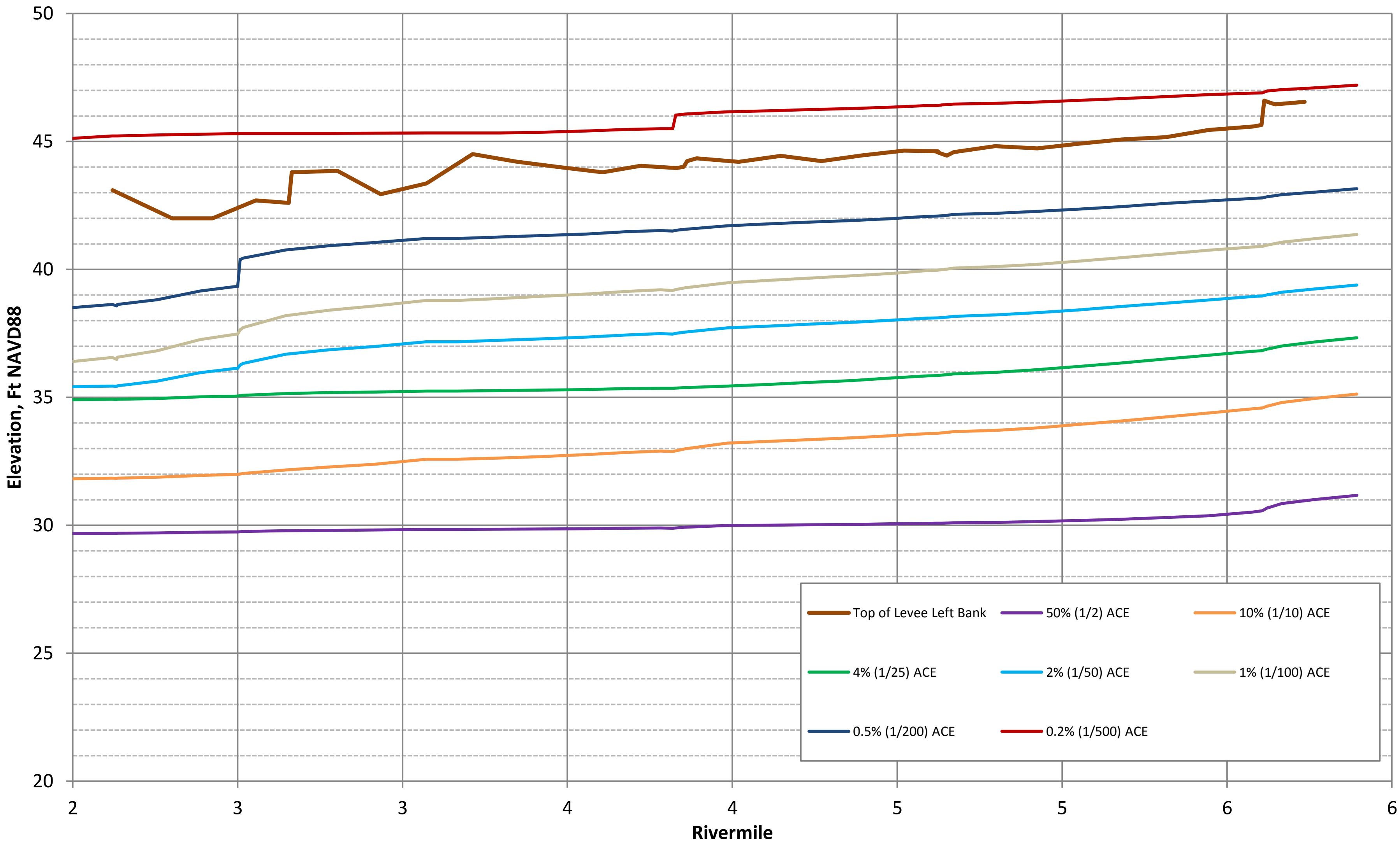


American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District

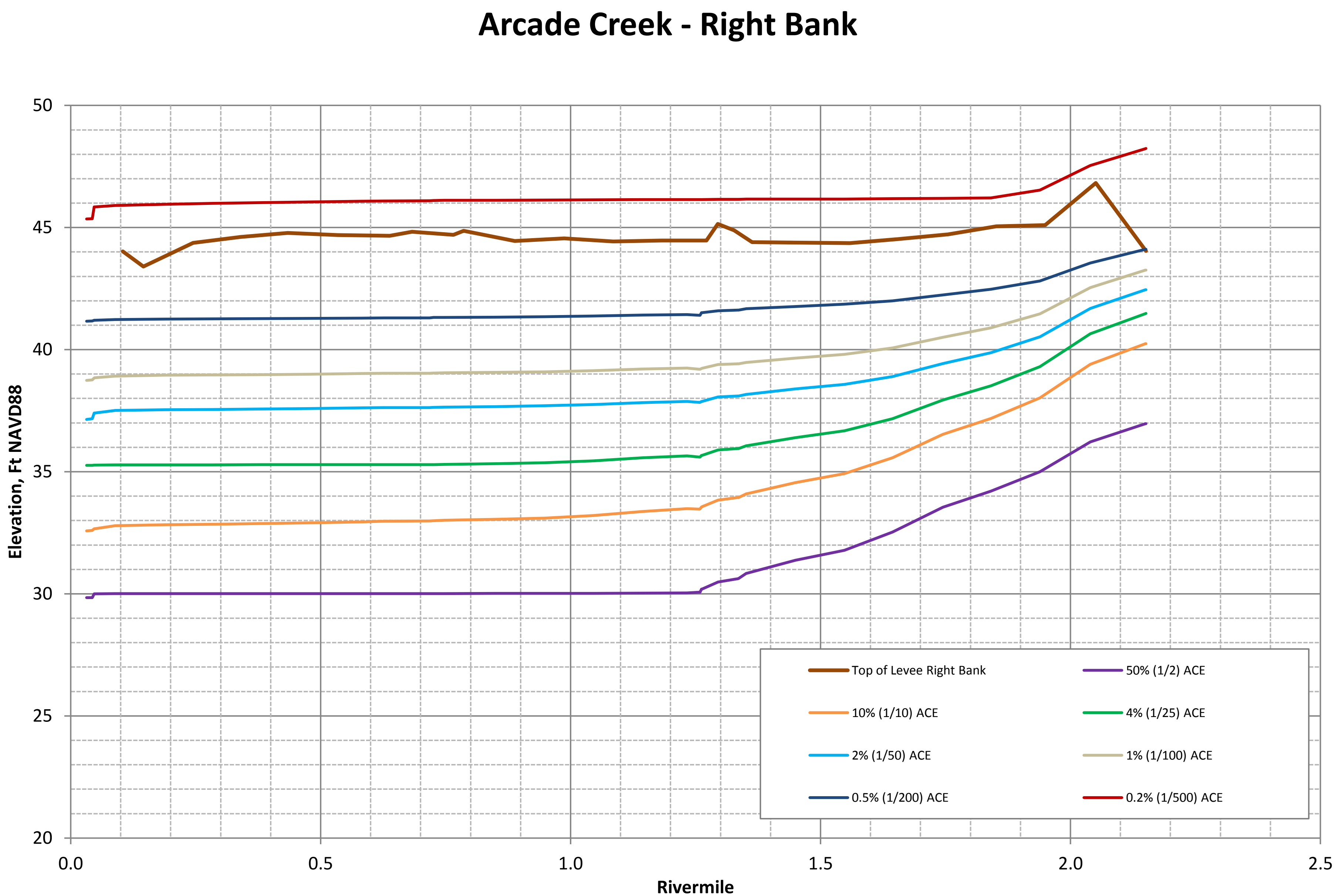


American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District

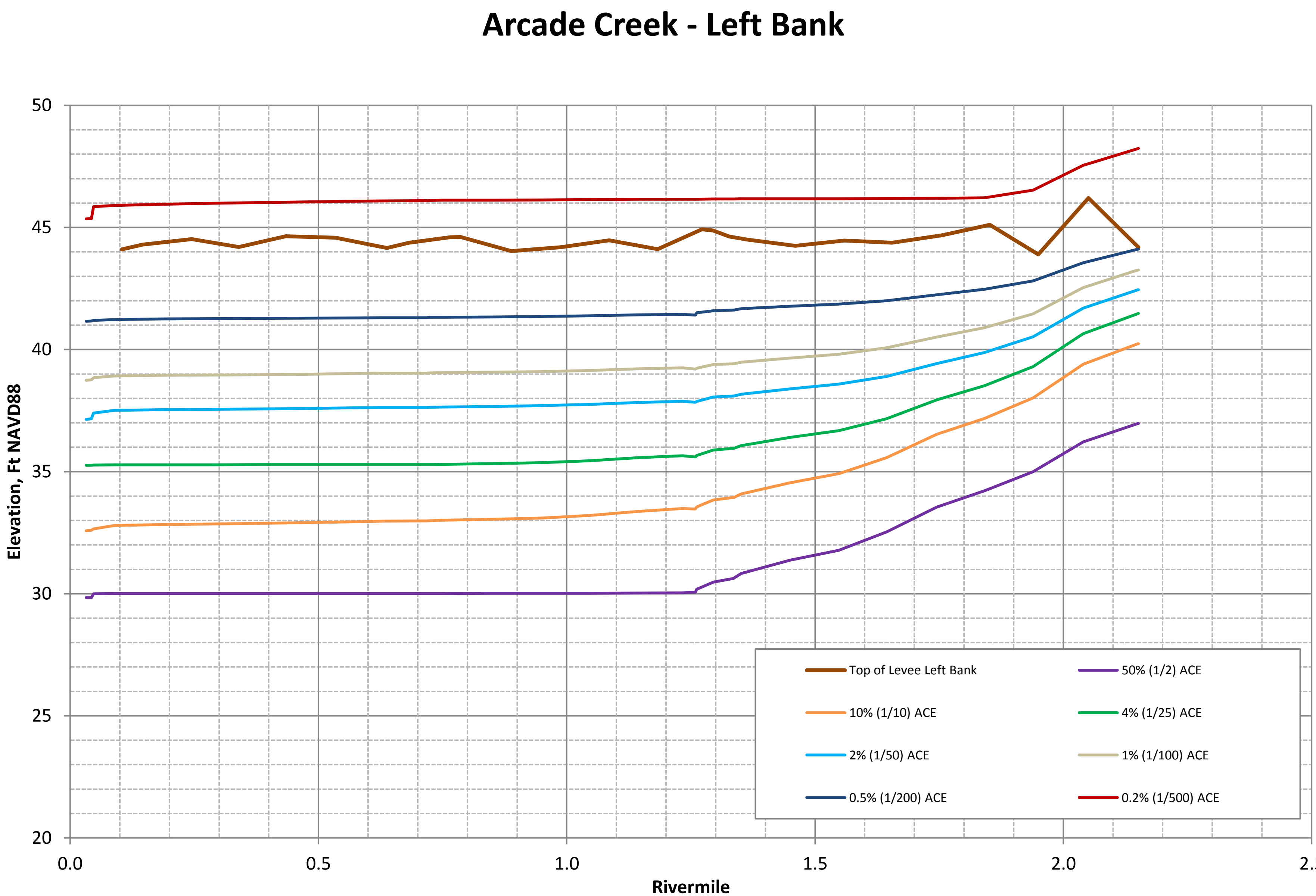
NEMDC - Left Bank



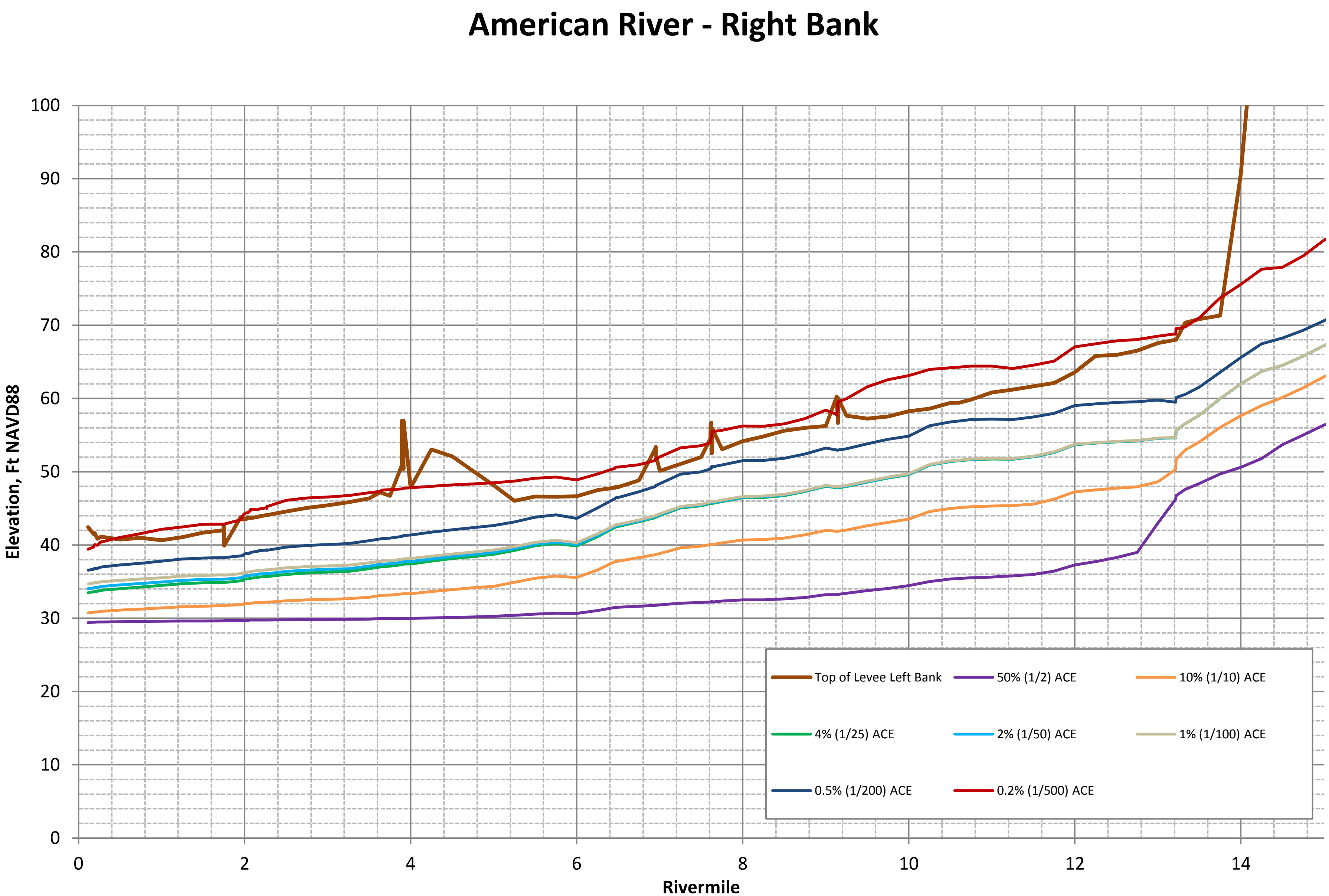
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



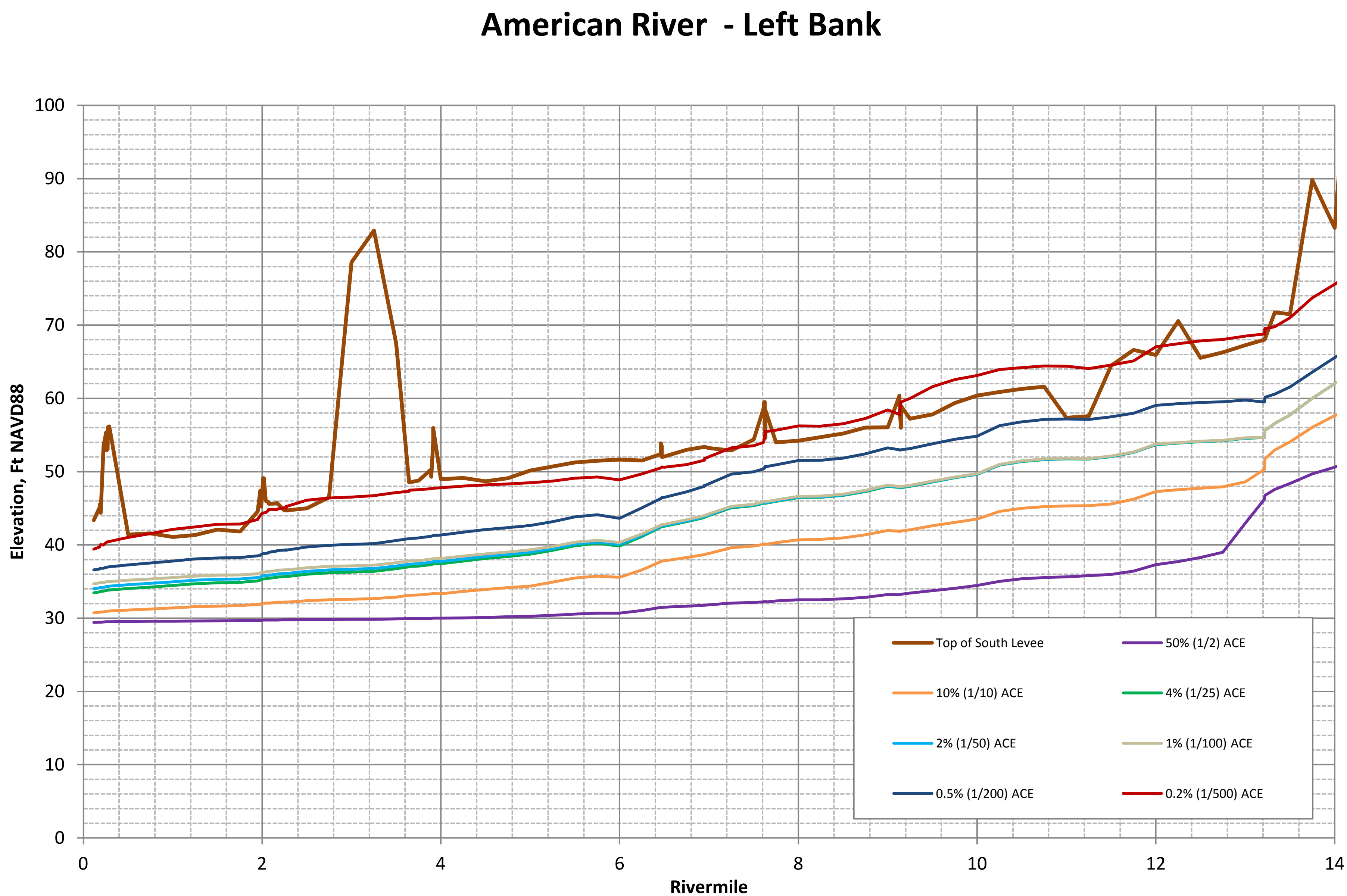
American River Common Features GRR Sacramento, California	Arcade Creek – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



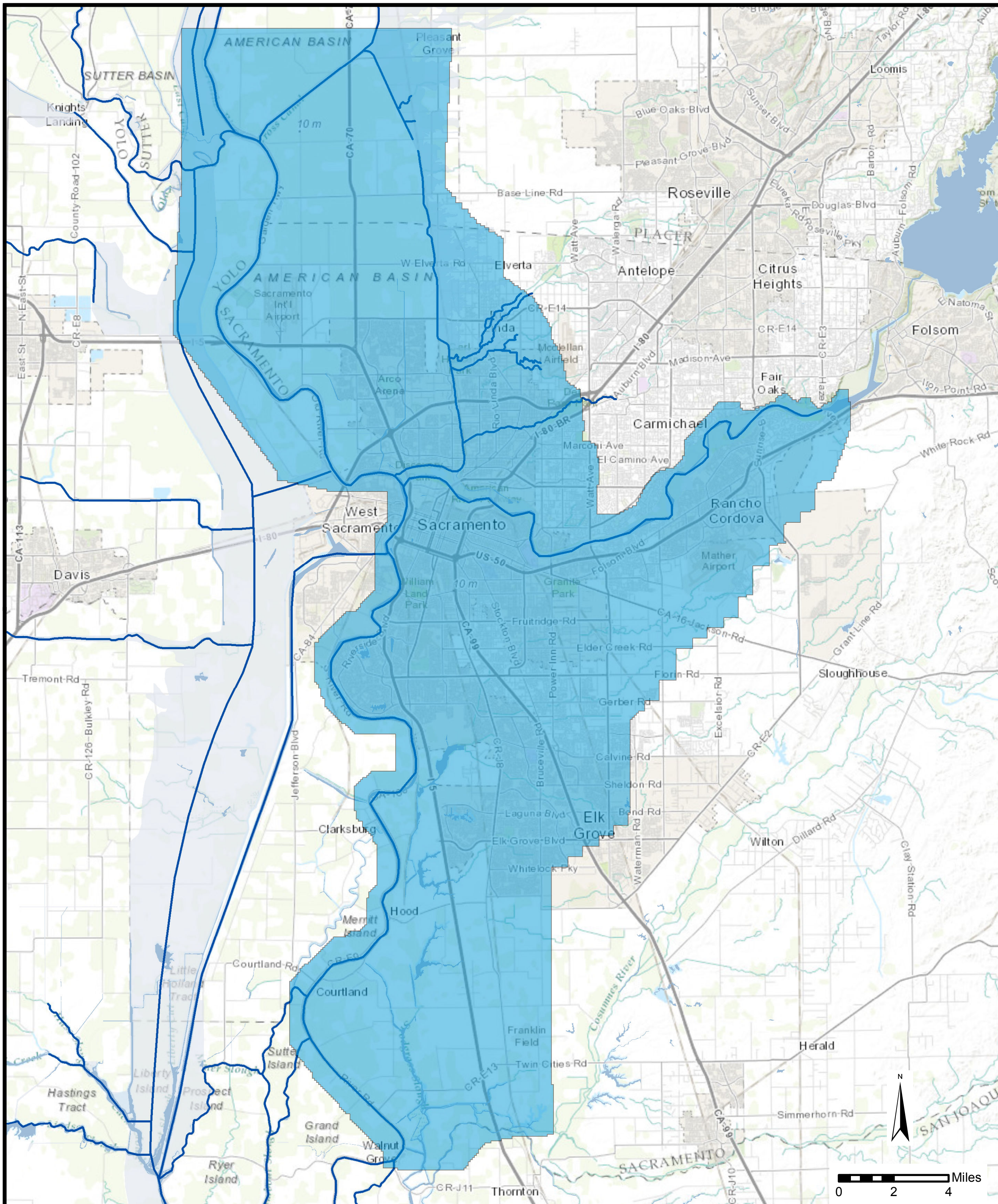
American River Common Features GRR Sacramento, California	Arcade Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



LEGEND

FLO2D Extents

Rivers and Streams

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

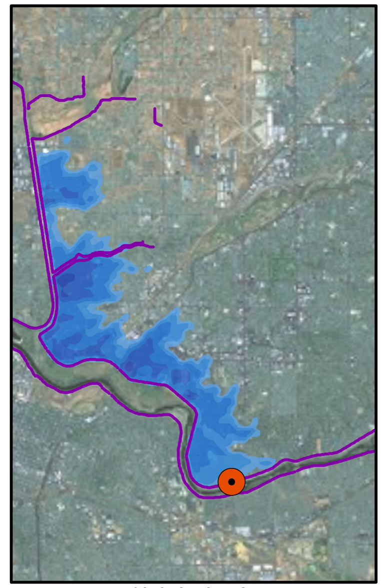
FLO2D MODEL EXTENTS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

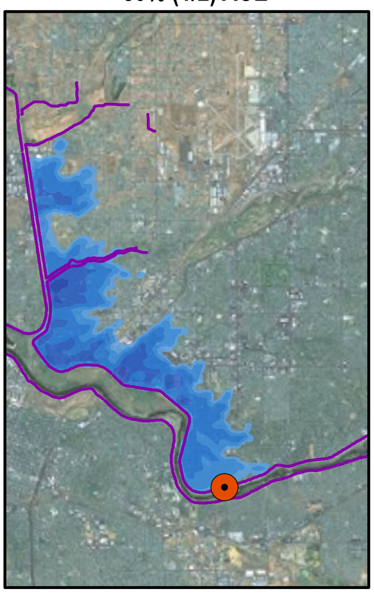
Jan 2013

50% (1/2) ACE

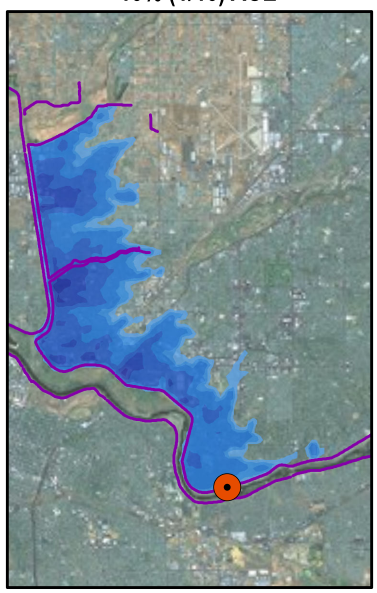
10% (1/10) ACE



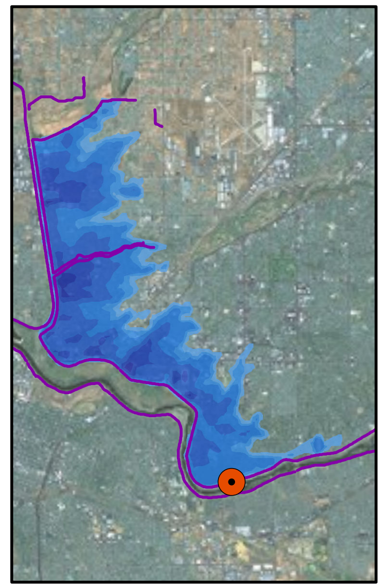
4% (1/25) ACE



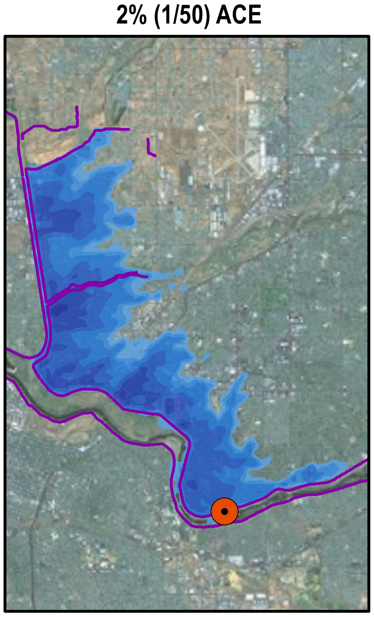
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE

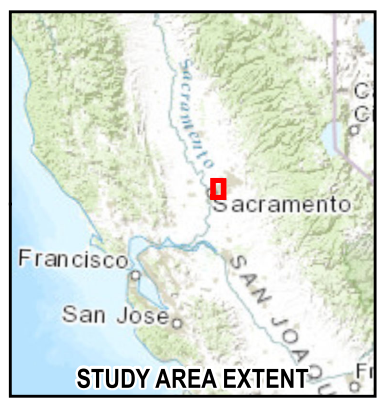


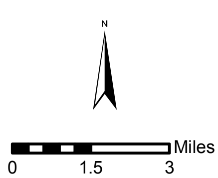
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



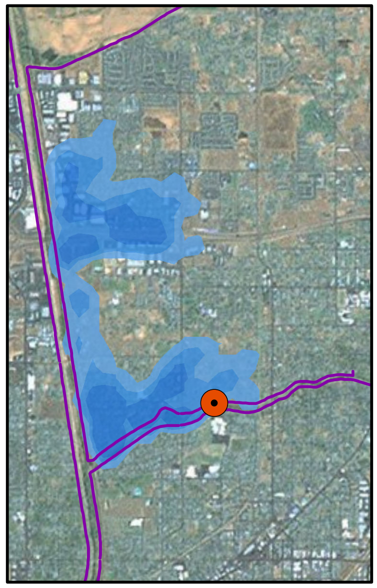


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

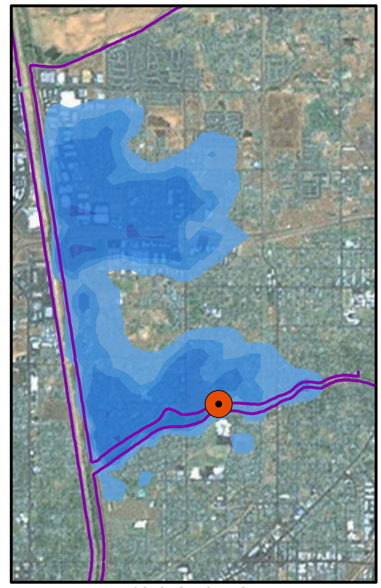
ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER NORTH INDEX PT A.

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

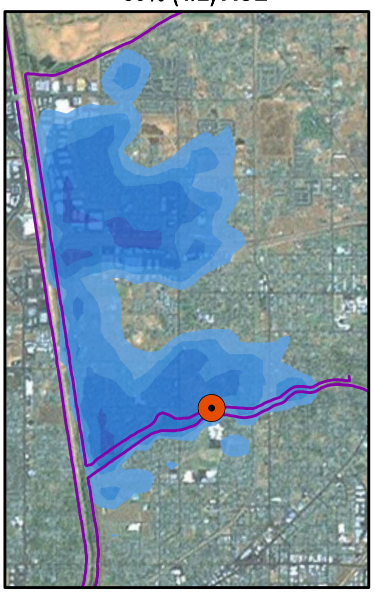
50% (1/2) ACE



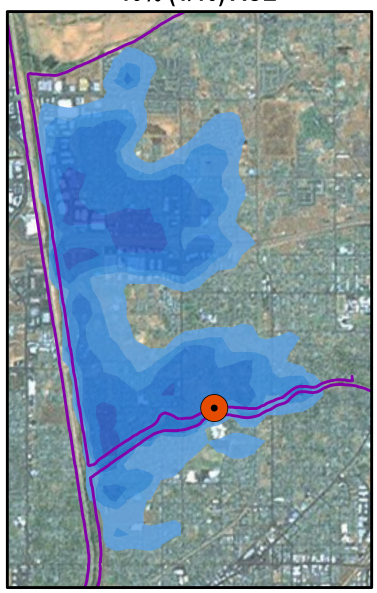
10% (1/10) ACE



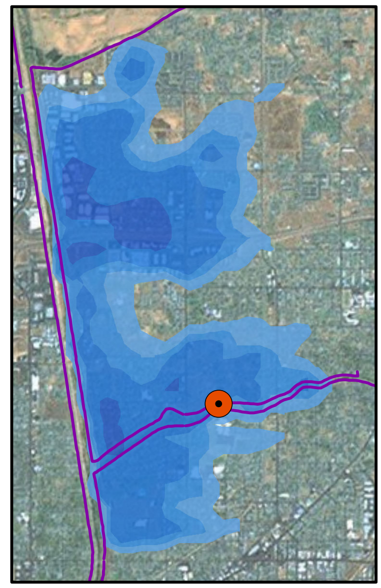
4% (1/25) ACE



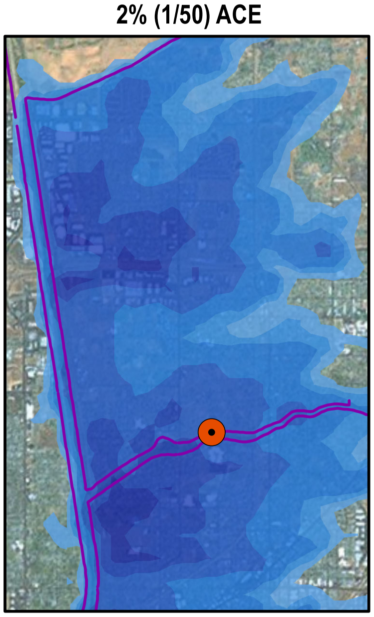
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE

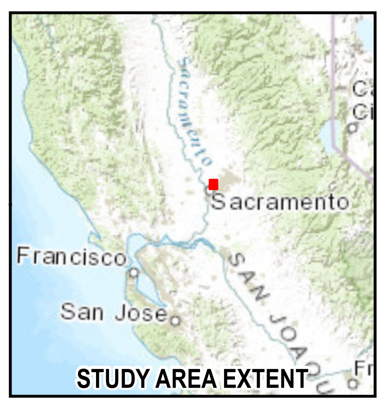


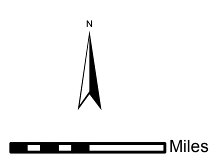
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



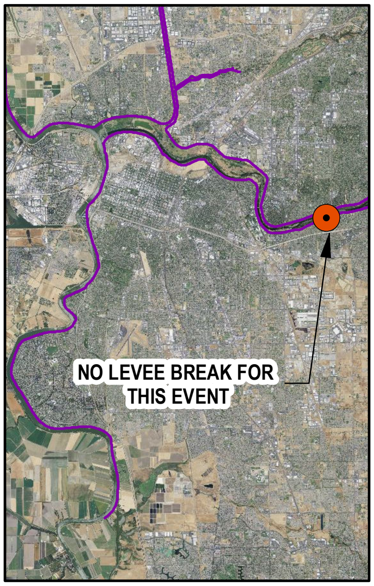


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

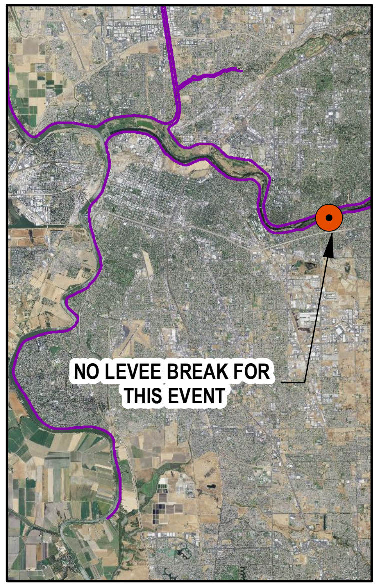
ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER NORTH INDEX PT E.

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

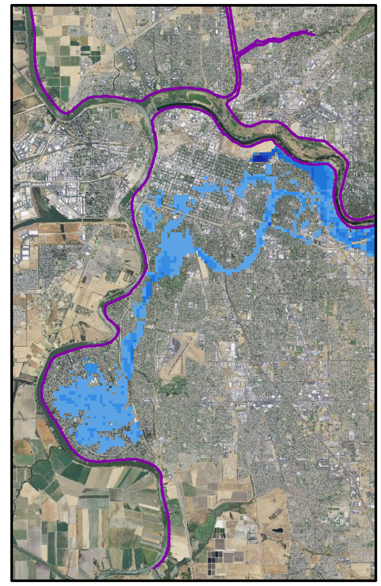
Feb 2013



50% (1/2) ACE



10% (1/10) ACE



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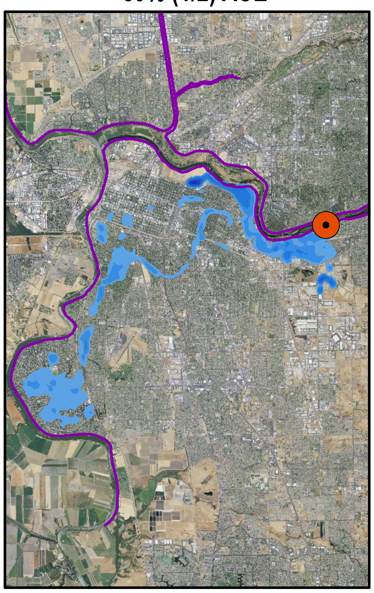
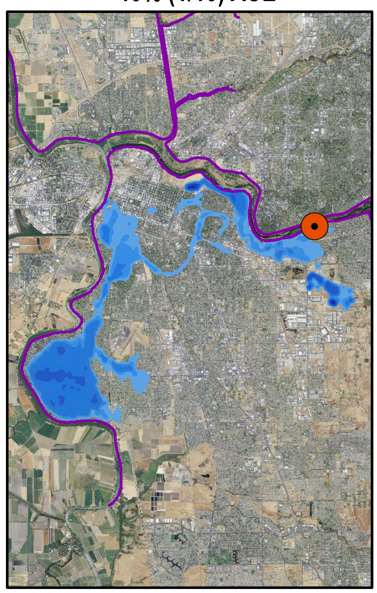
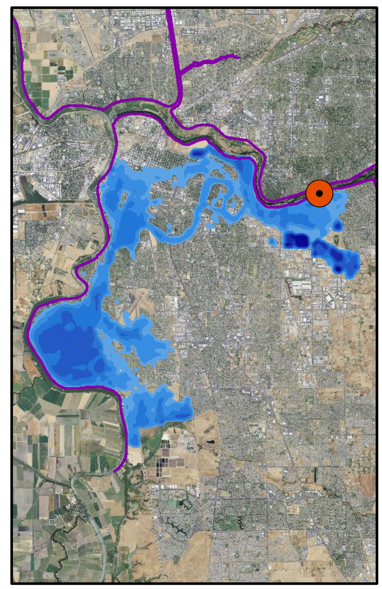


2% (1/50) ACE



1% (1/100) ACE



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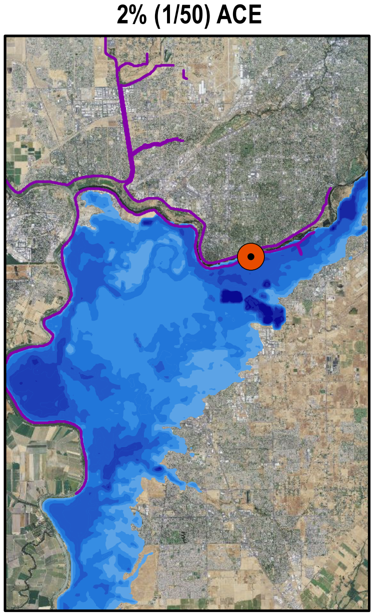
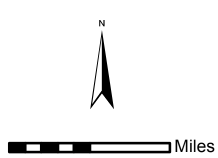


0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

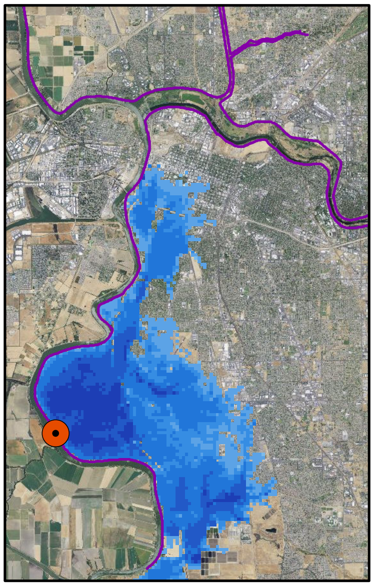
- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



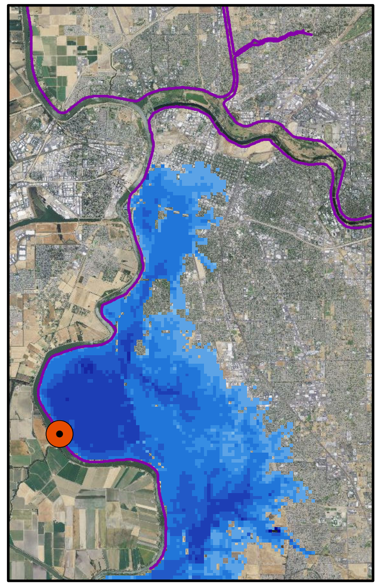
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER SOUTH INDEX PT A.

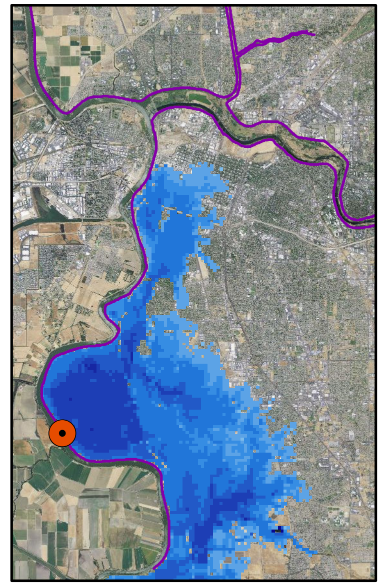
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



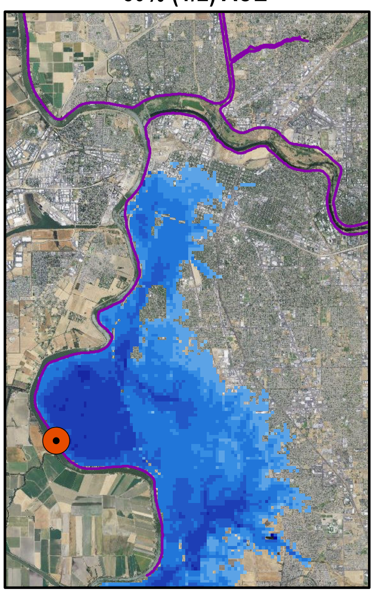
50% (1/2) ACE



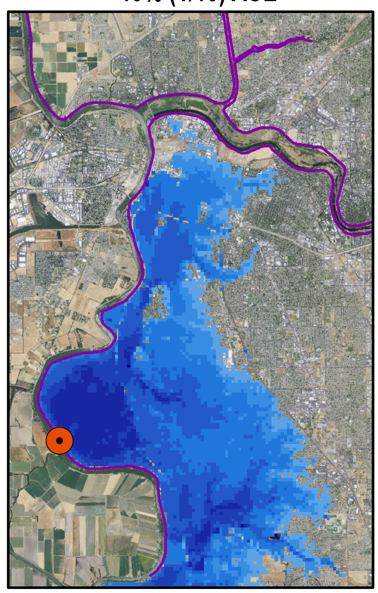
10% (1/10) ACE



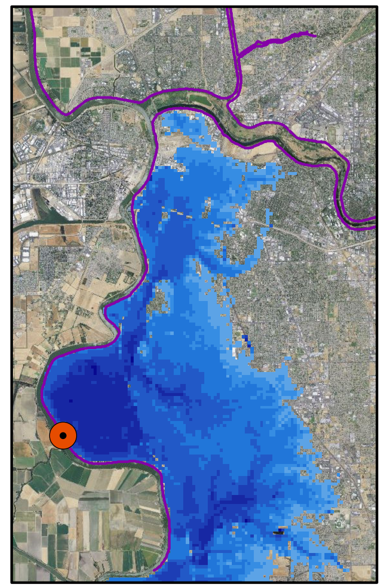
4% (1/25) ACE



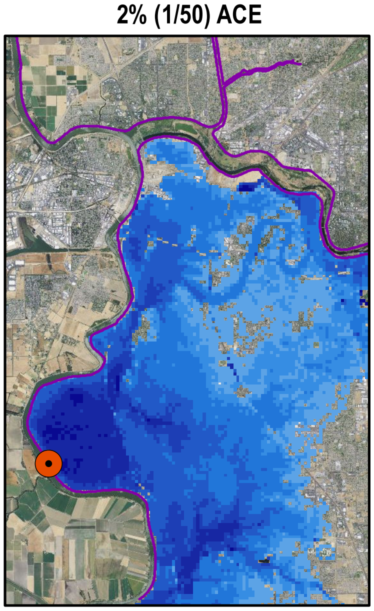
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



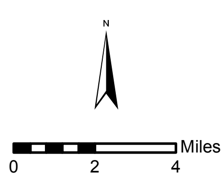
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +

STUDY AREA EXTENT

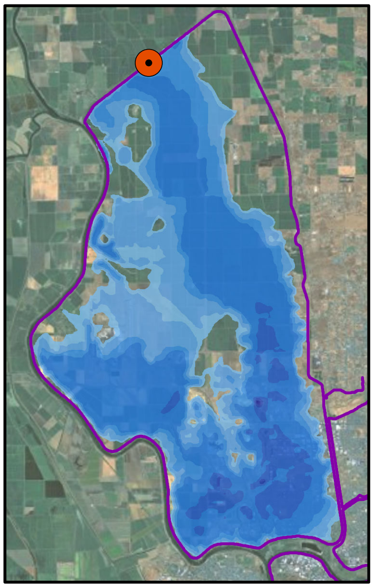


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

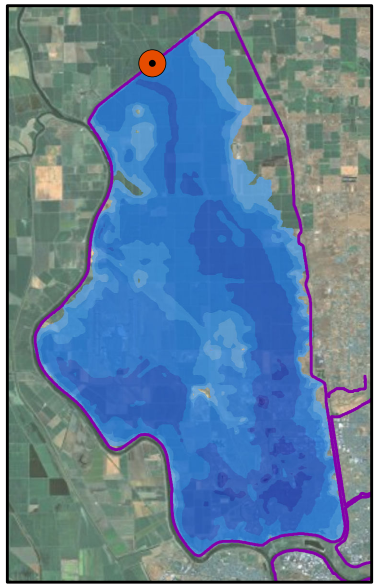
ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER SOUTH INDEX PT F.

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

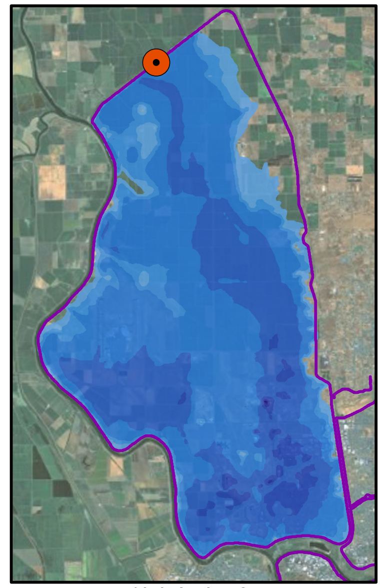
June 2014



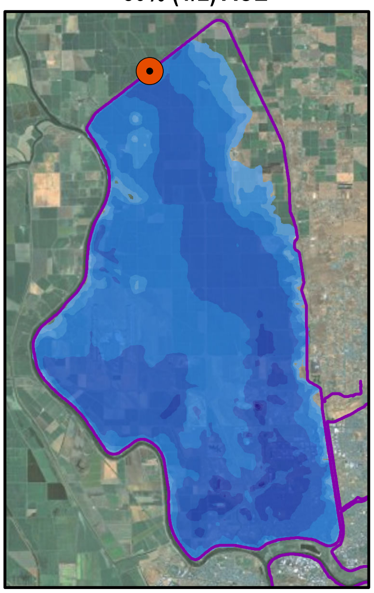
50% (1/2) ACE



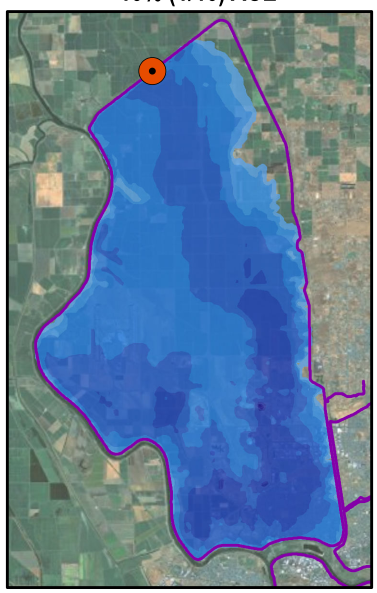
10% (1/10) ACE



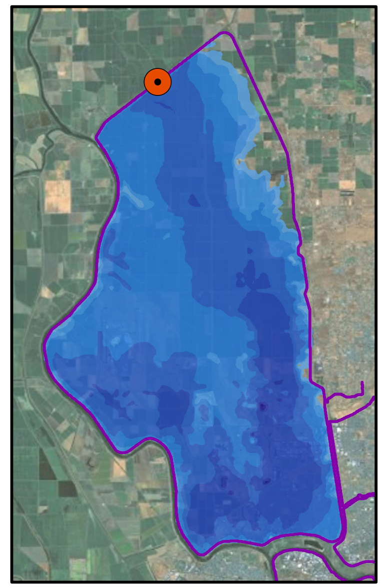
4% (1/25) ACE



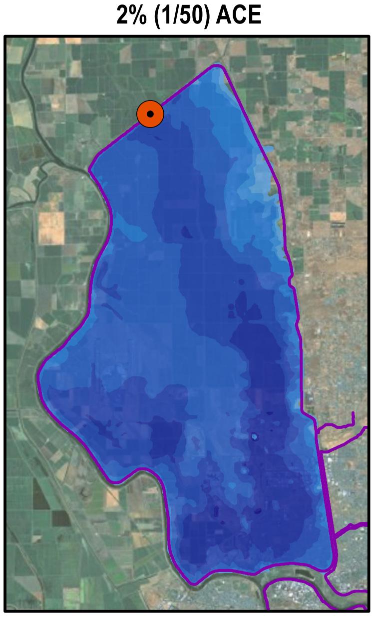
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE

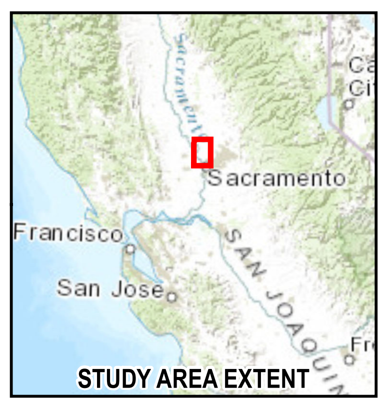


0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



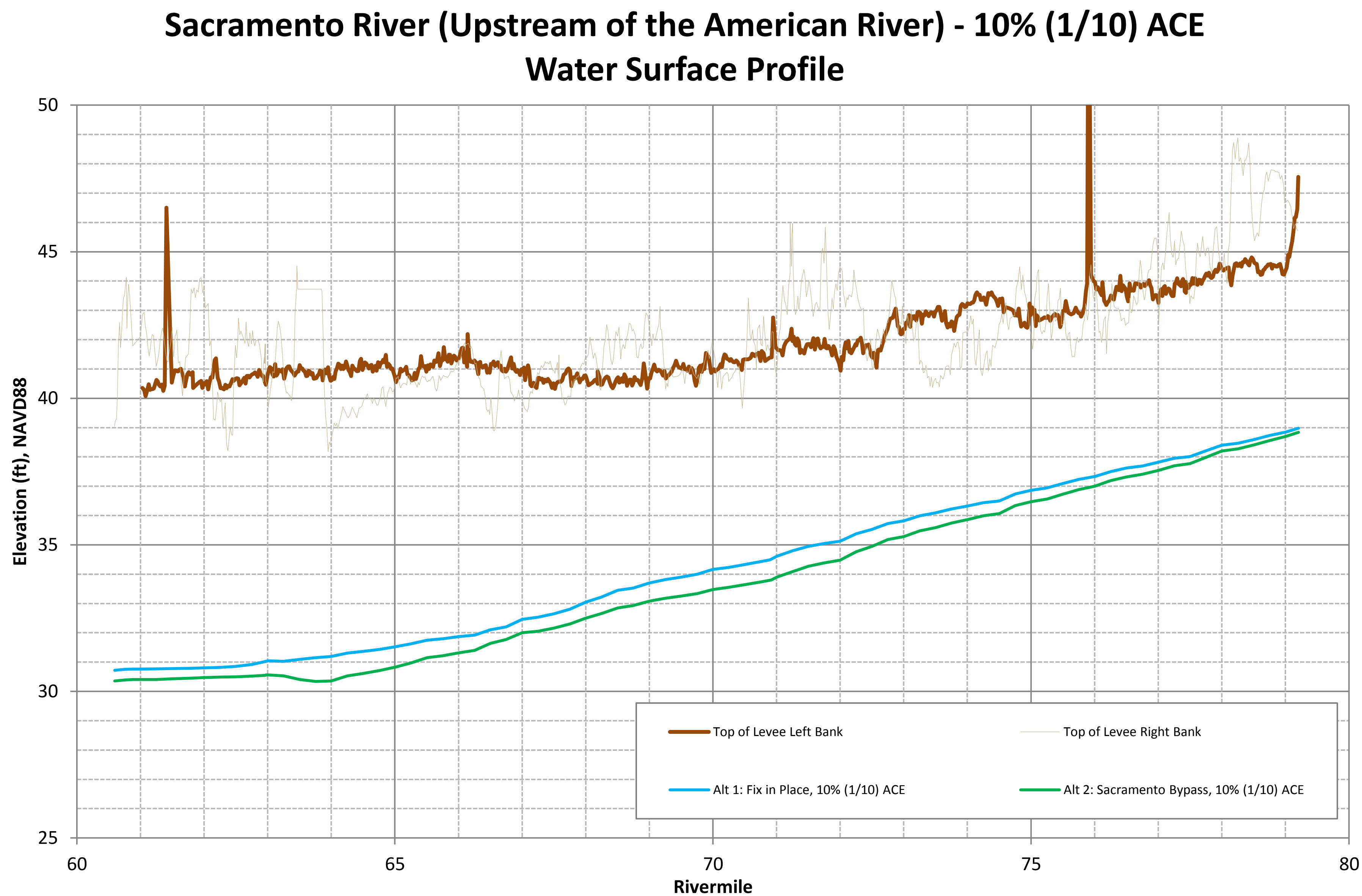
N

Miles
0 2.5 5

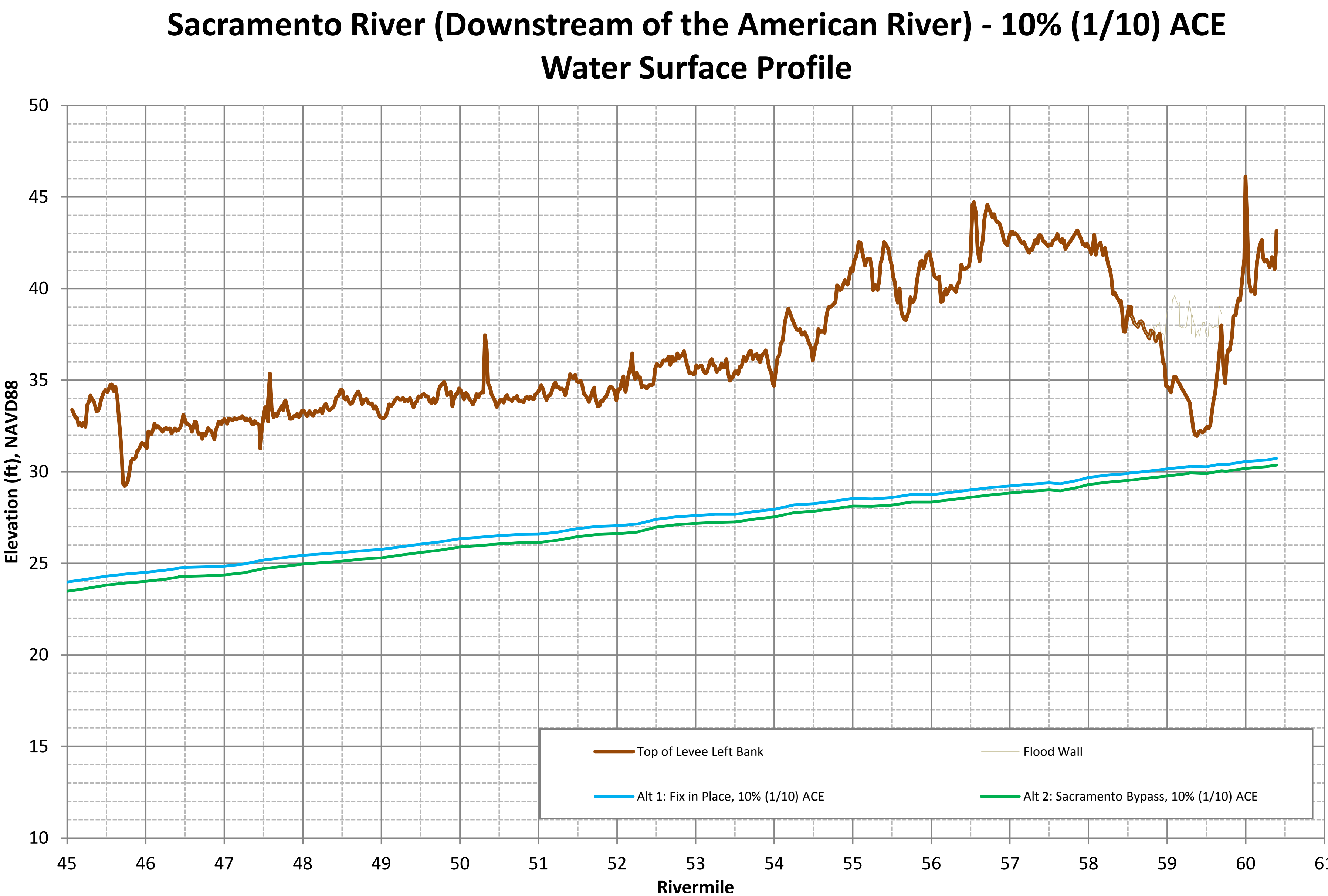
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION NATOMAS BASIN INDEX PT D.

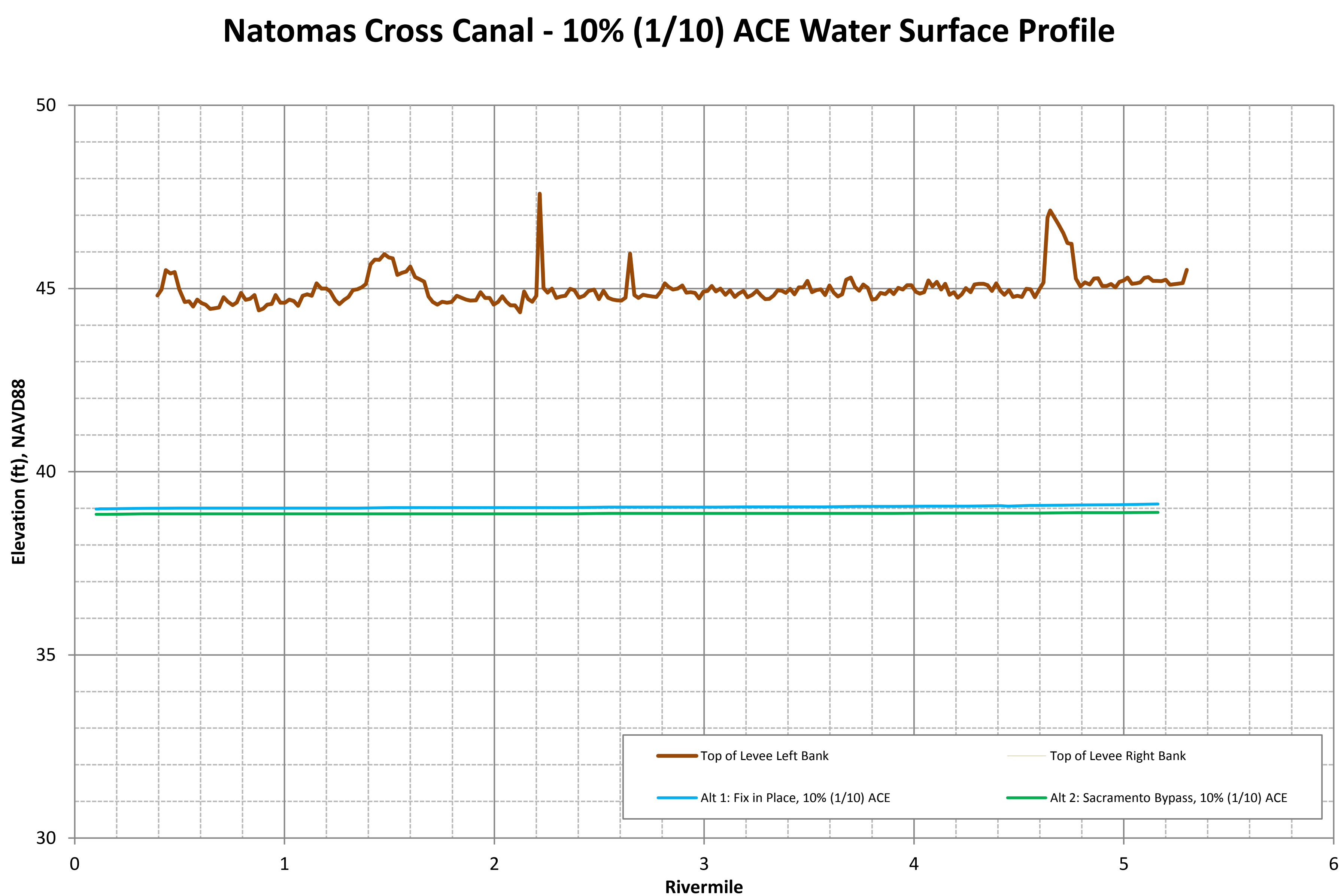
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



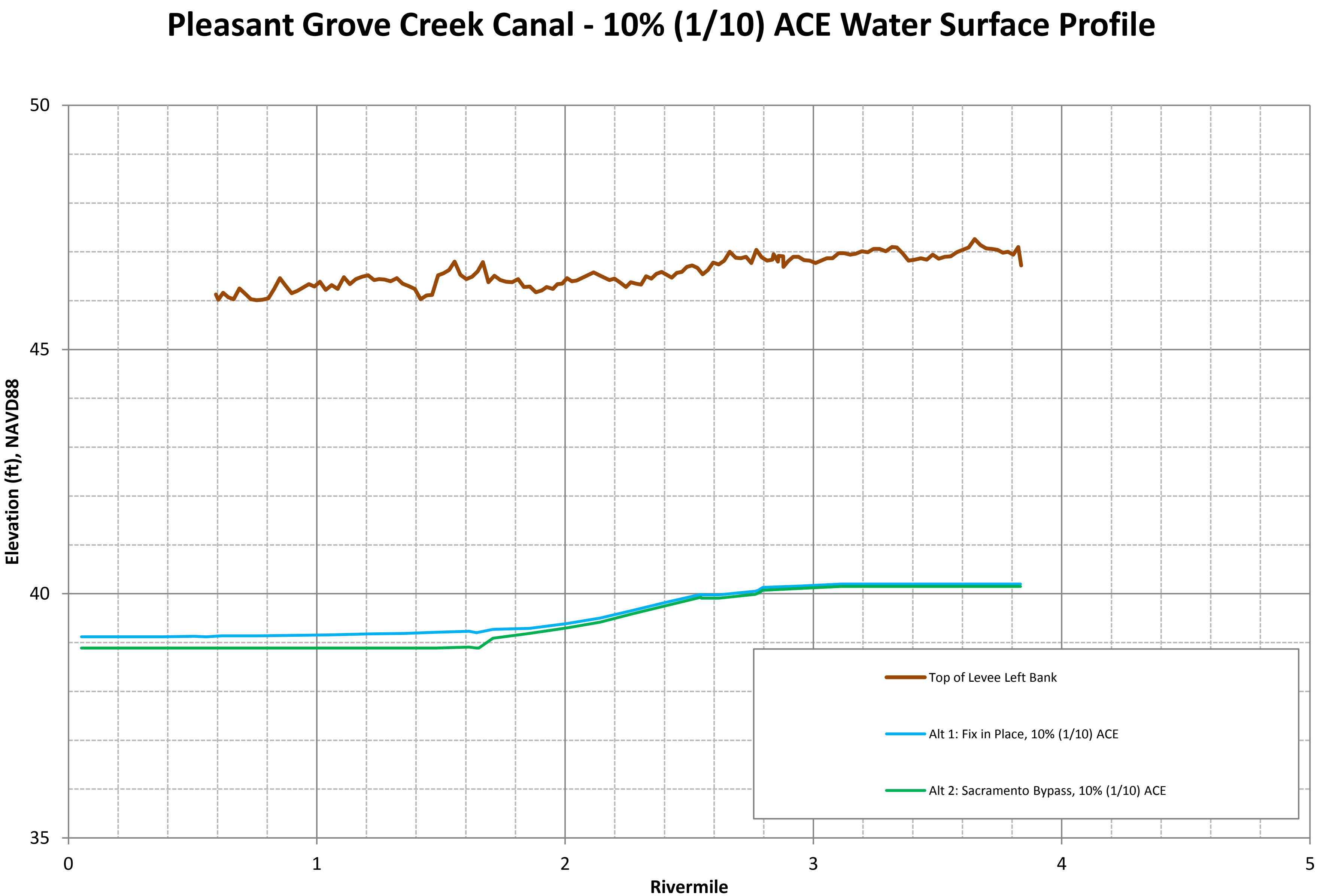
American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



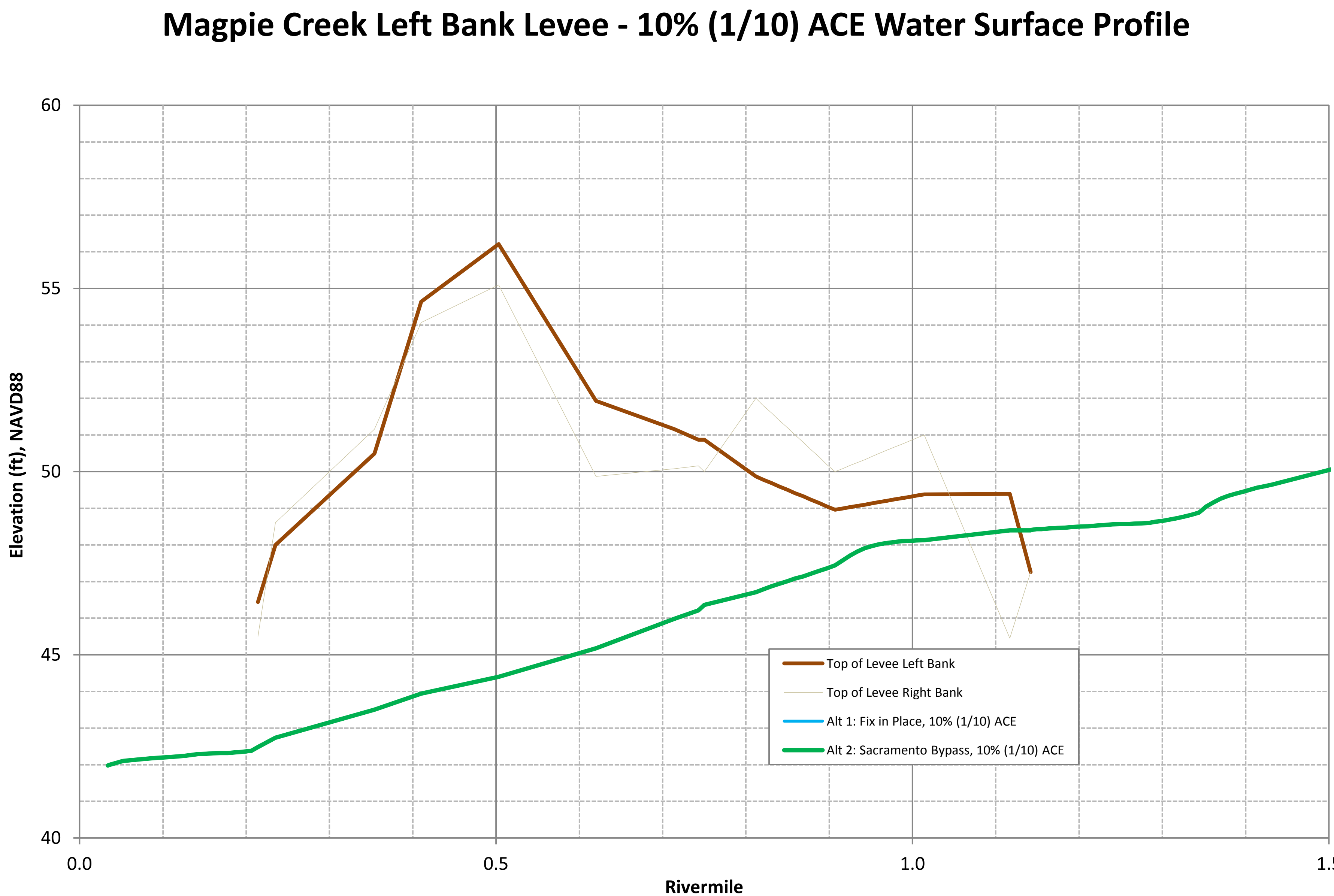
American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



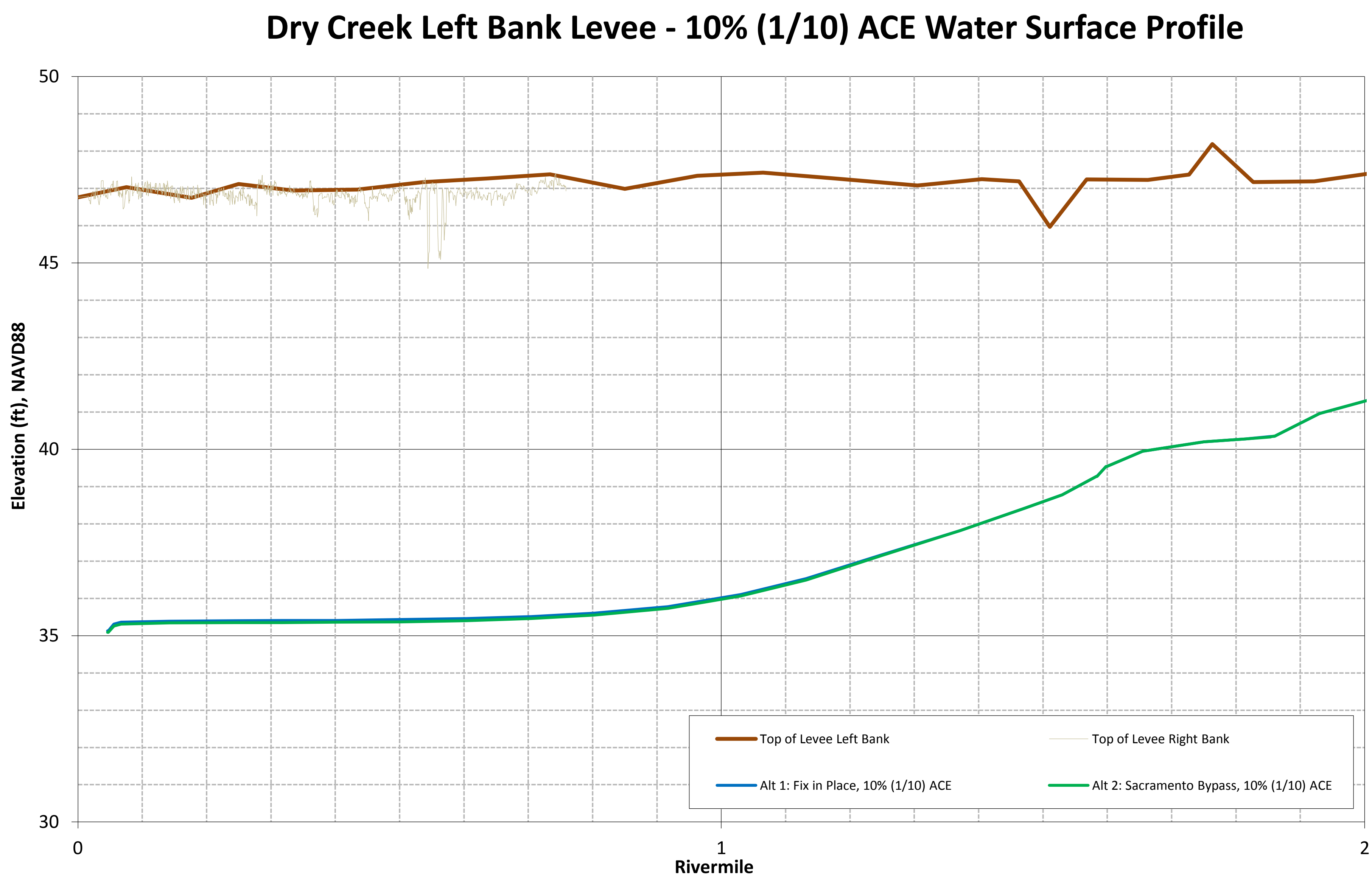
American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

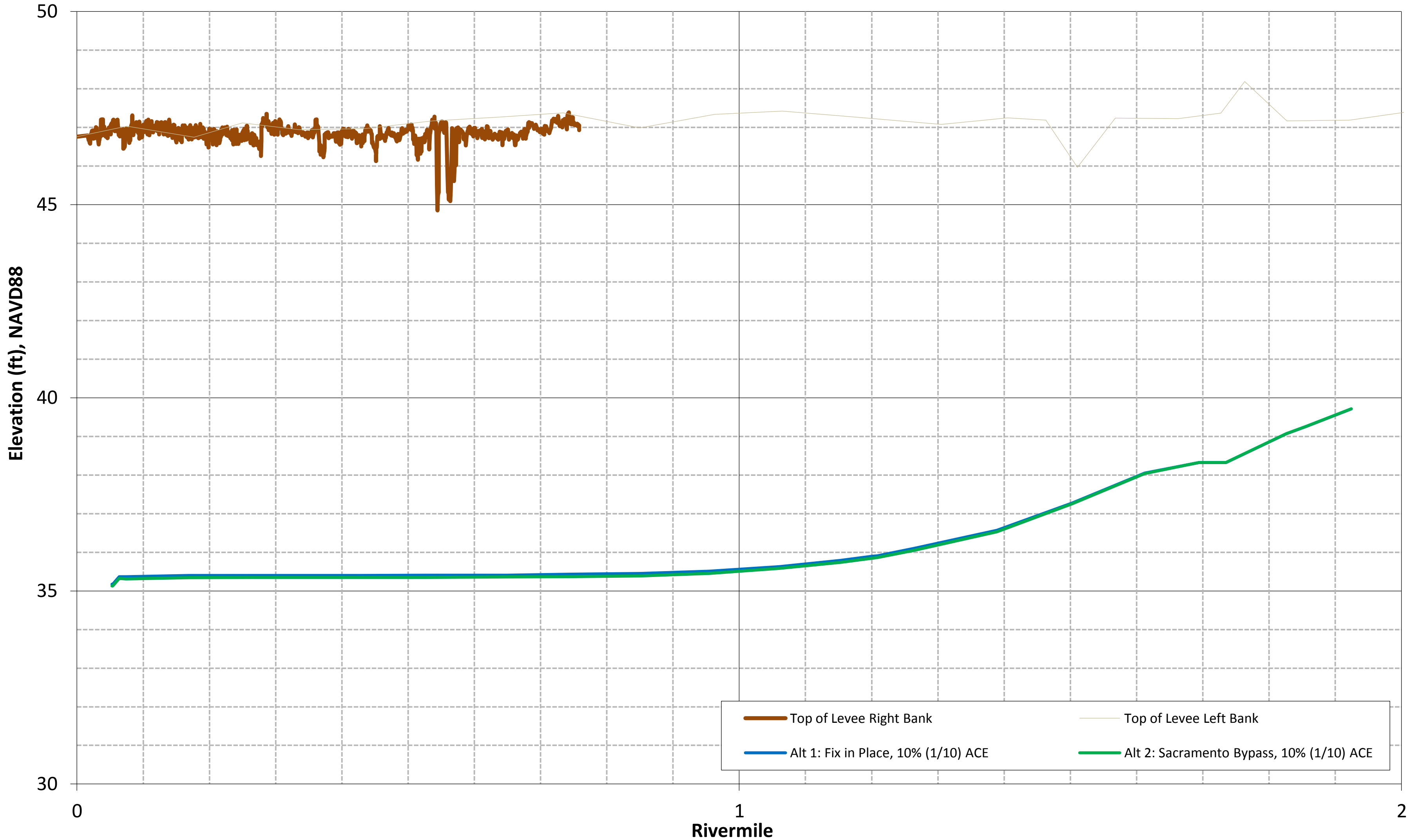


American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

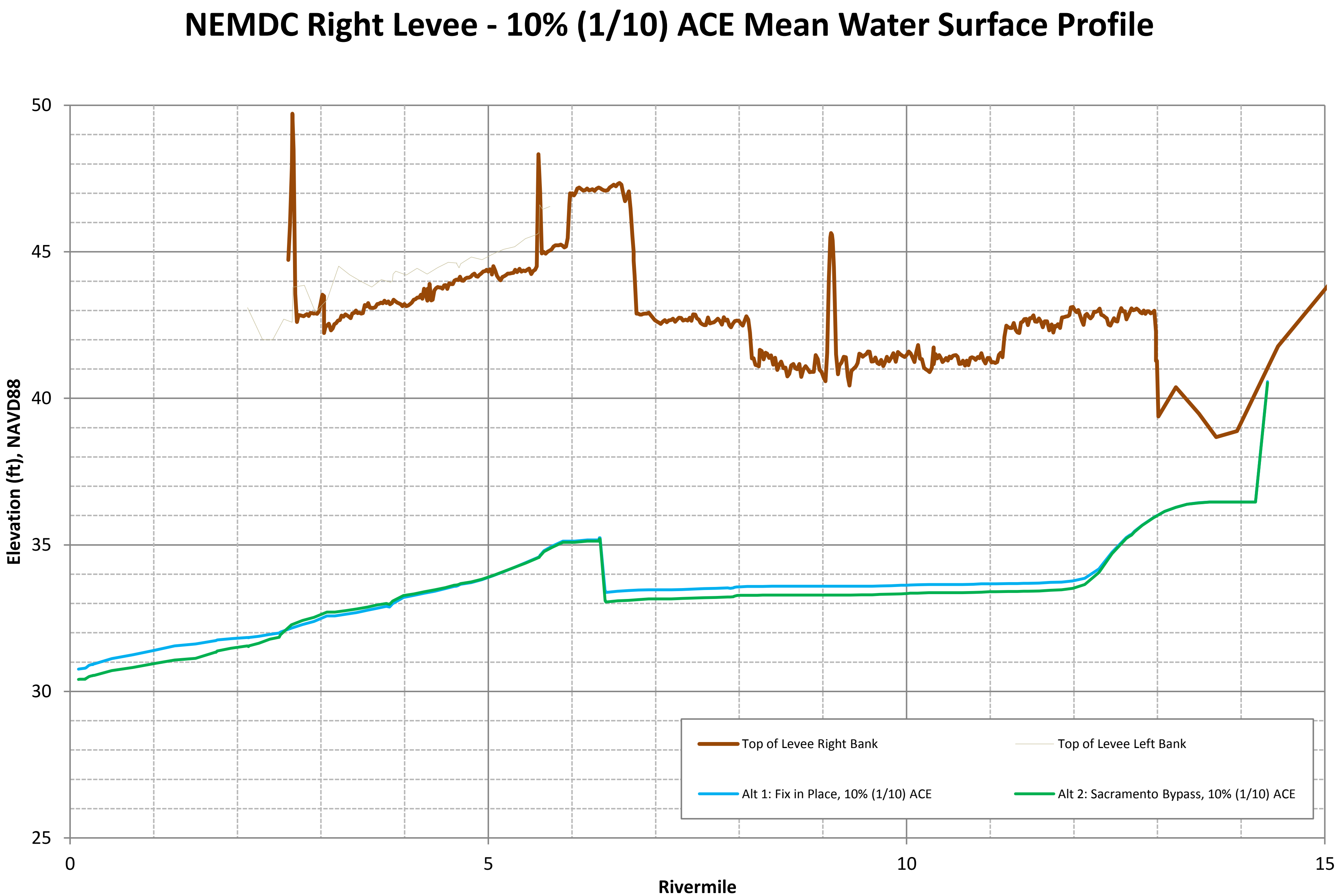


American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

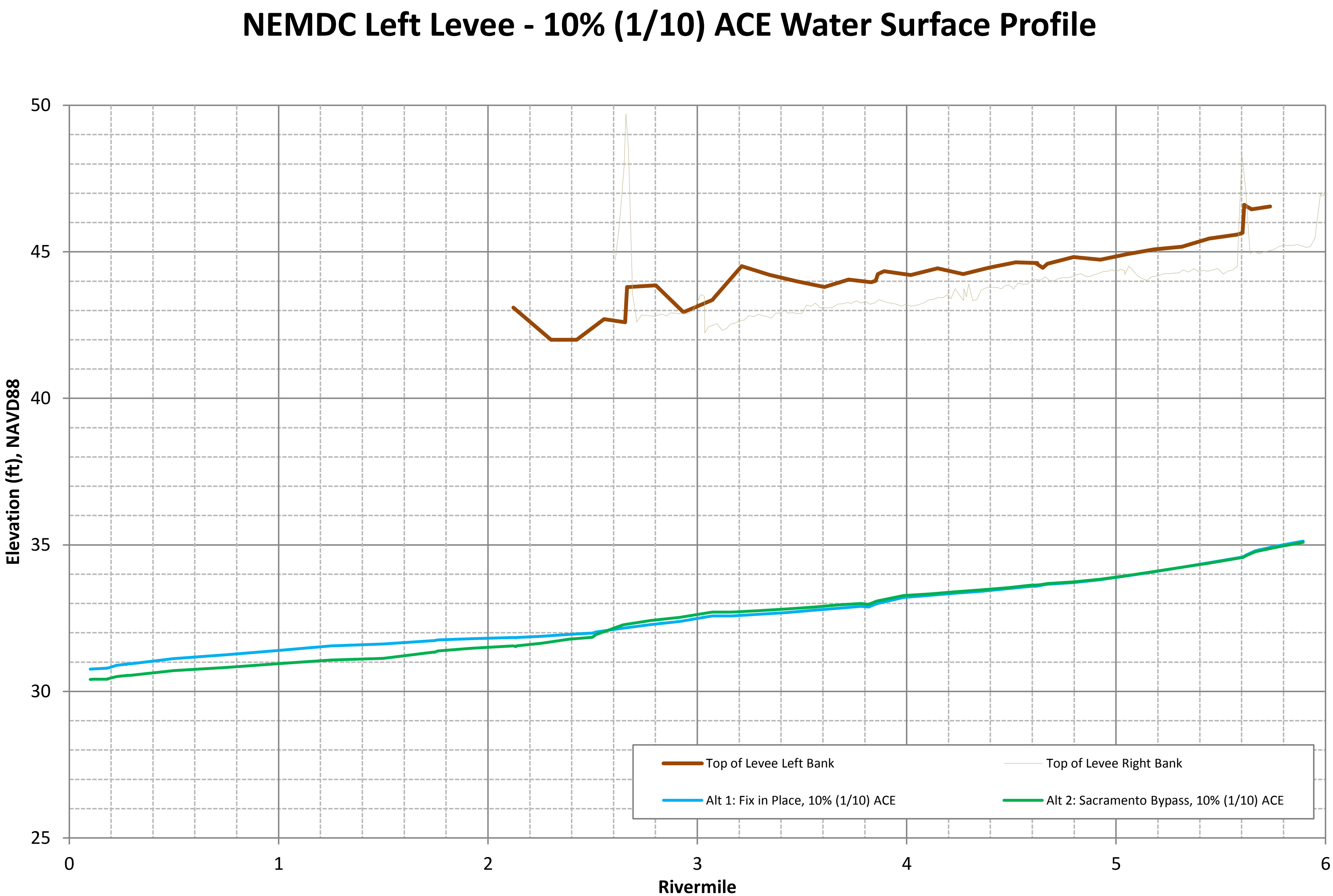
Dry Creek Right Bank Levee - 10% (1/10) ACE Water Surface Profile



American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

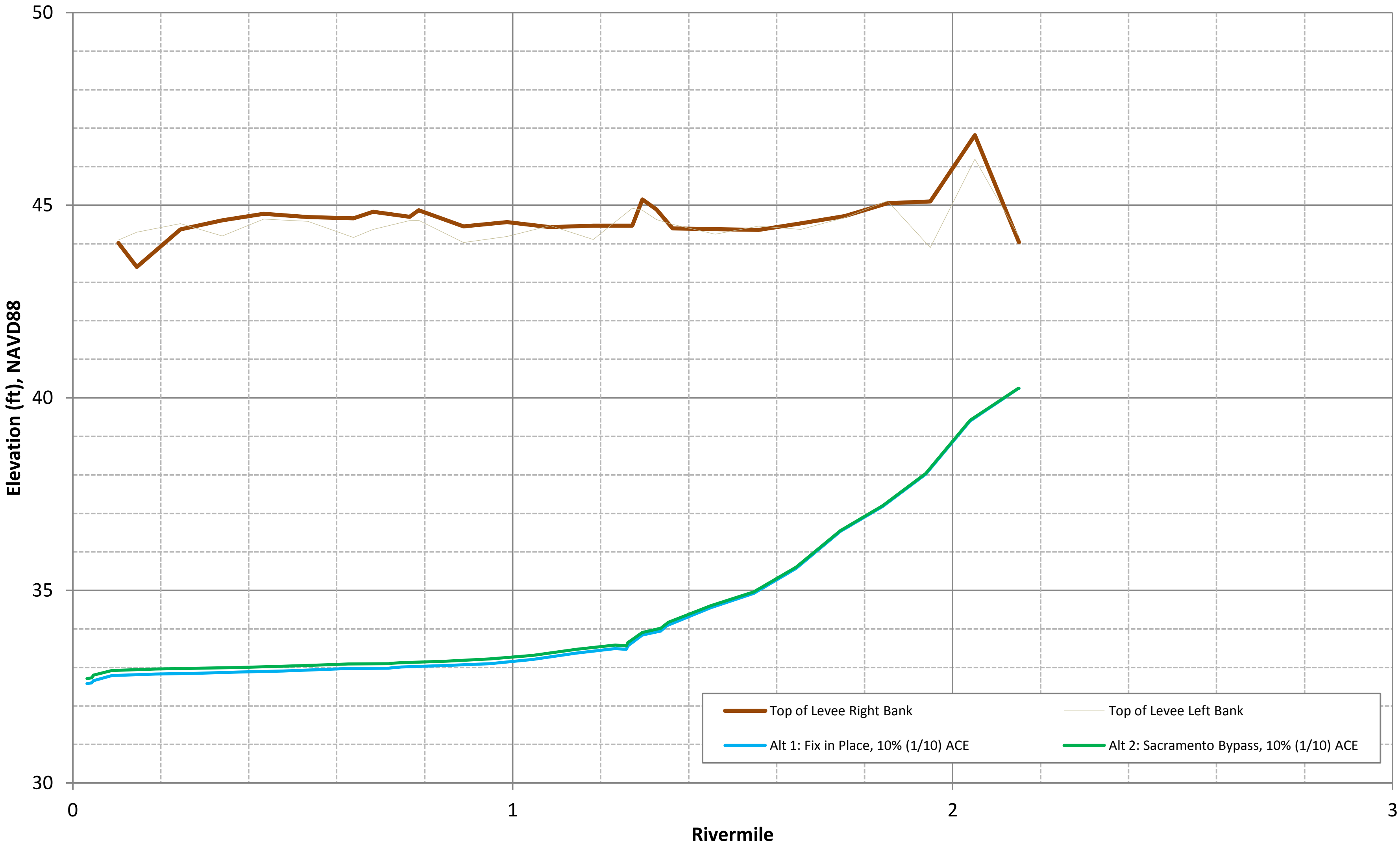


American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



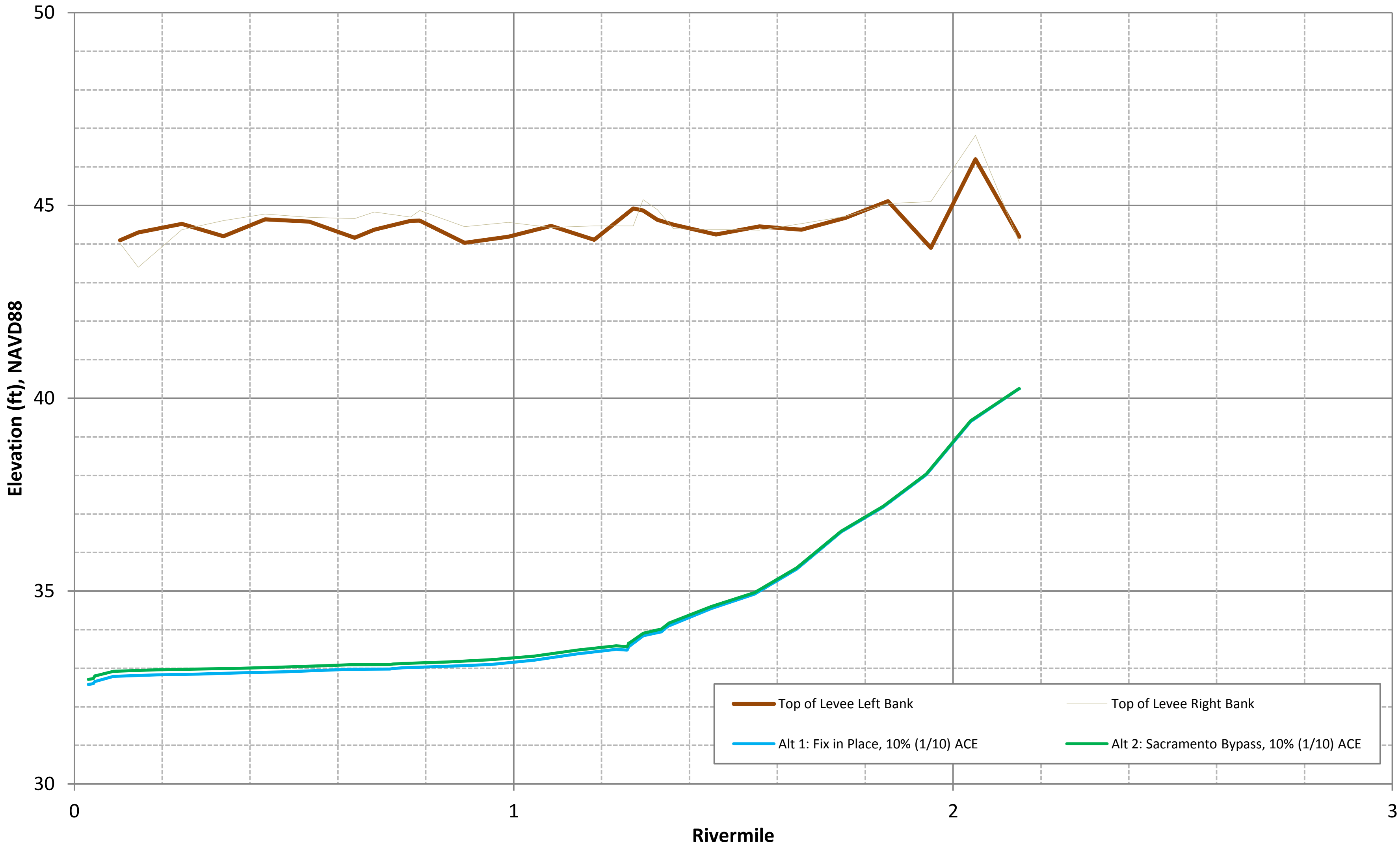
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Arcade Creek Right Bank Levee - 10% (1/10) ACE Water Surface Profile

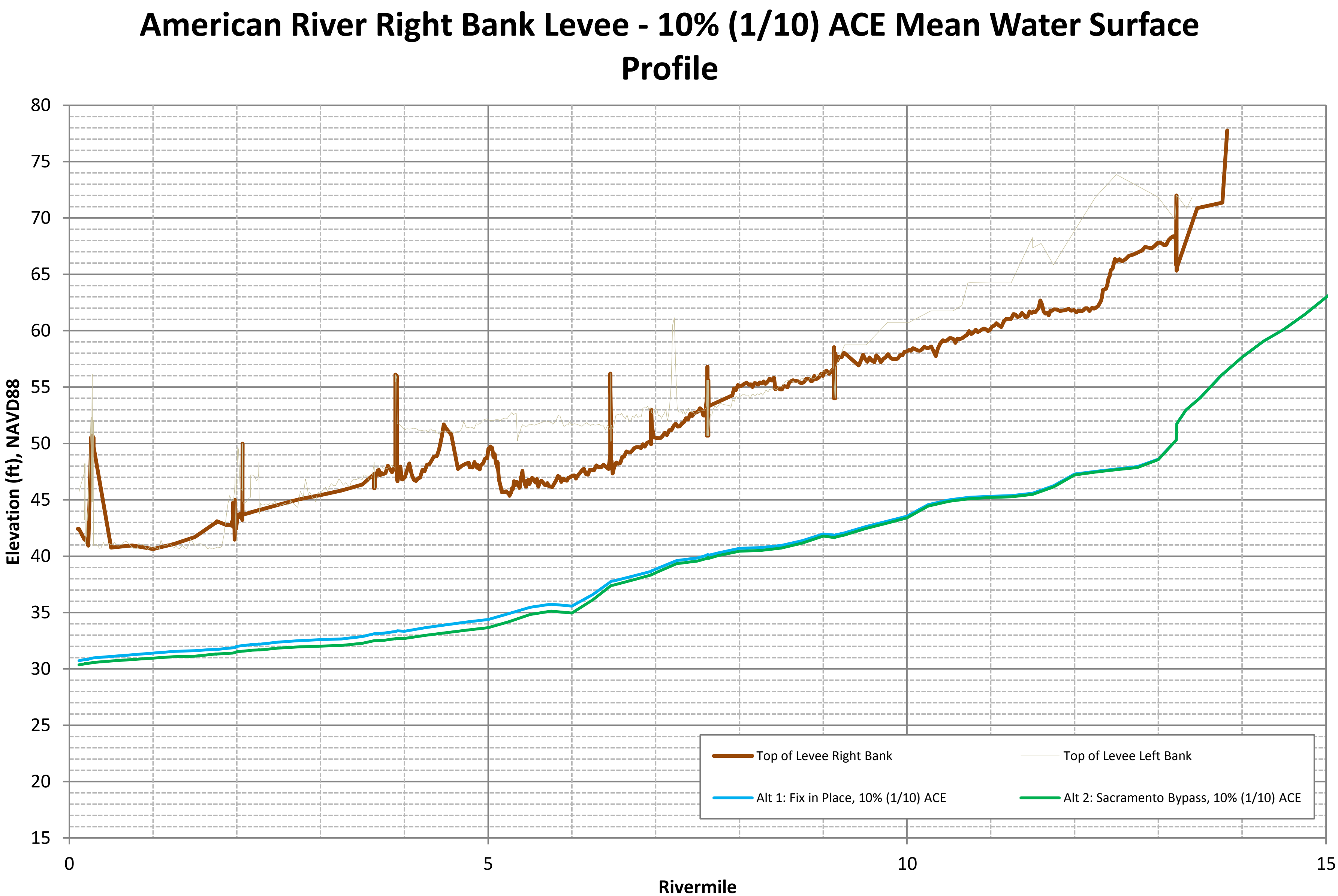


American River Common Features GRR Sacramento, California	Arcade Creek - Right Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Arcade Creek Left Bank Levee - 10% (1/10) ACE Water Surface Profile

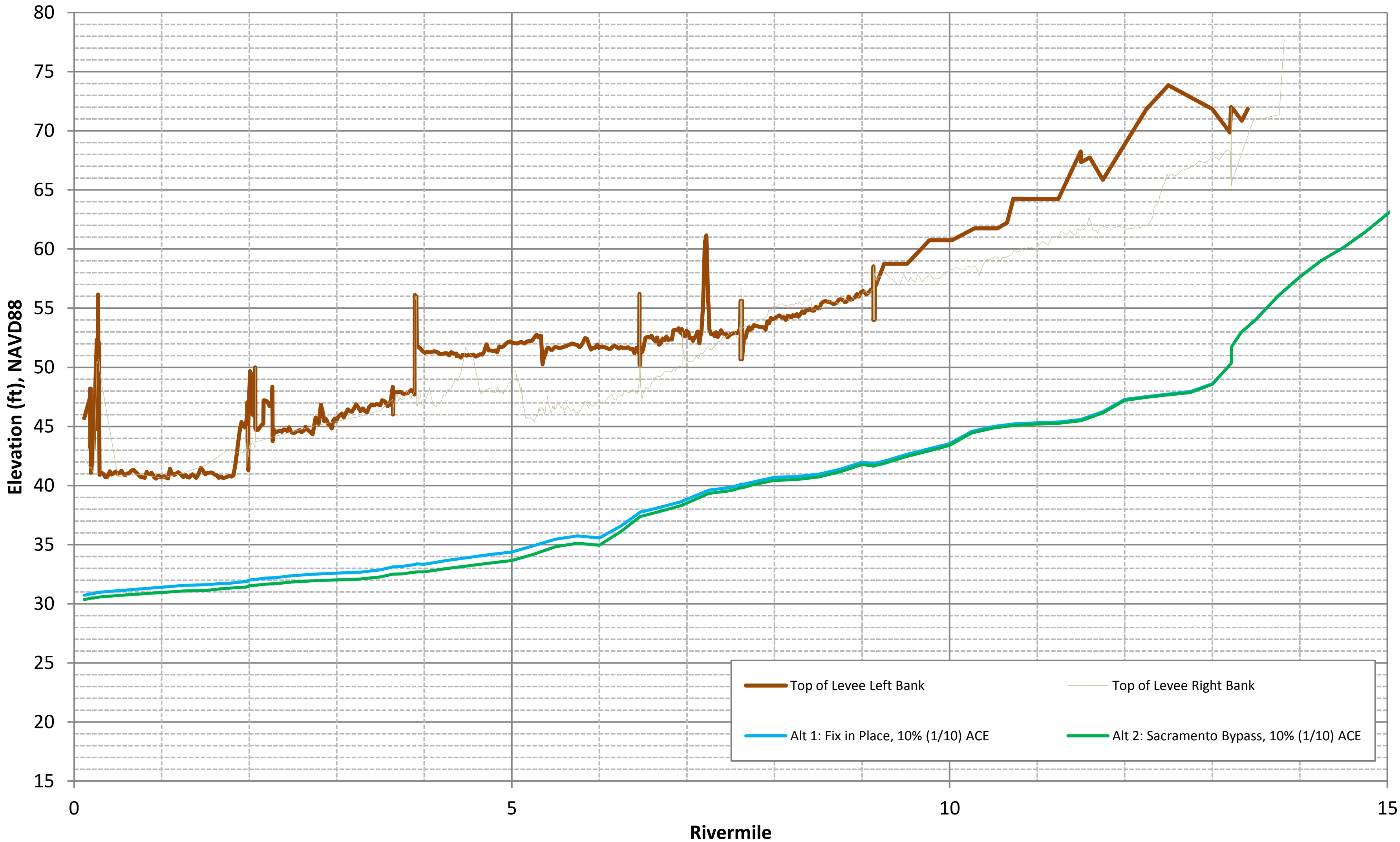


American River Common Features GRR Sacramento, California	Arcade Creek - Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

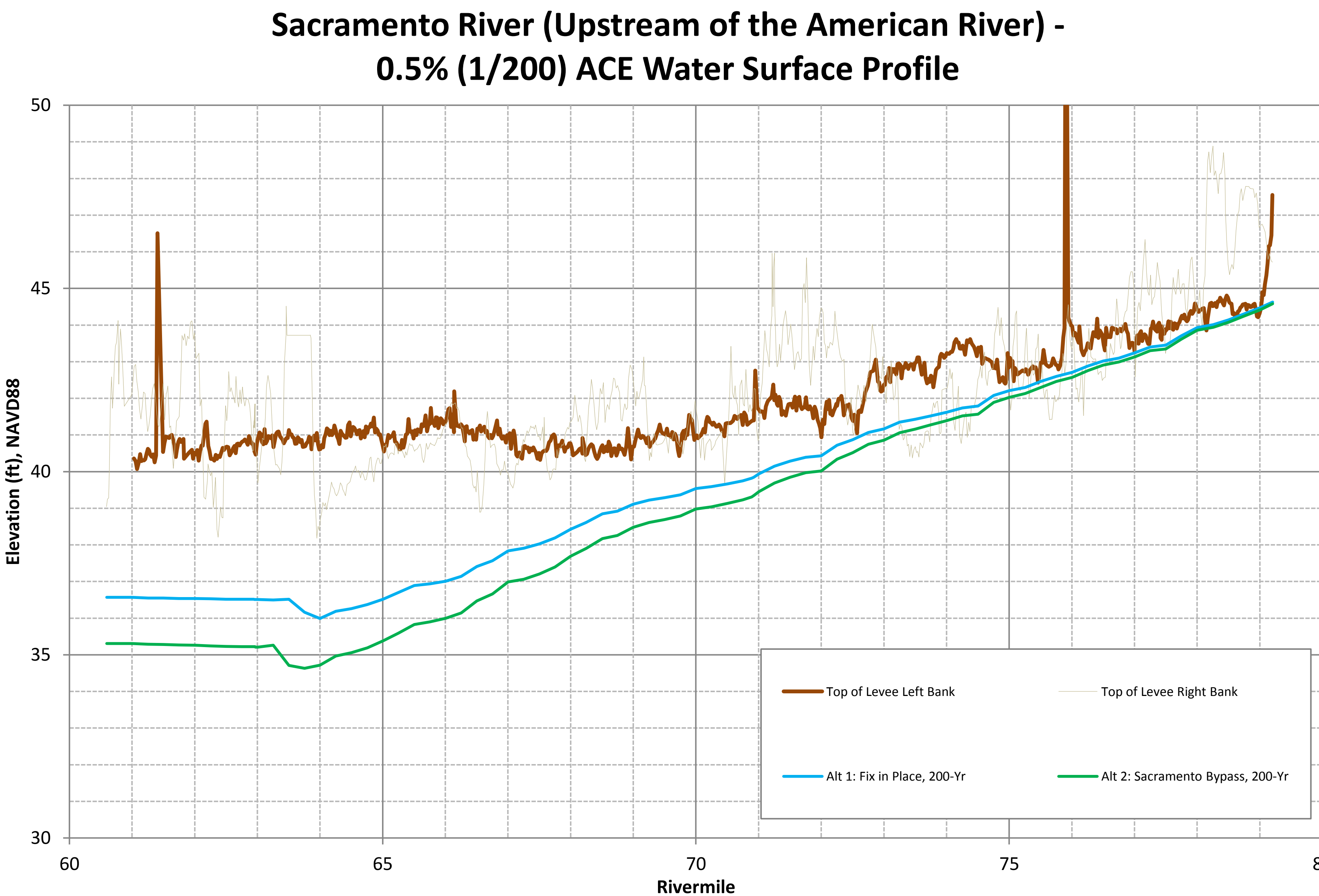


American River Common Features GRR Sacramento, California	American River – Right Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

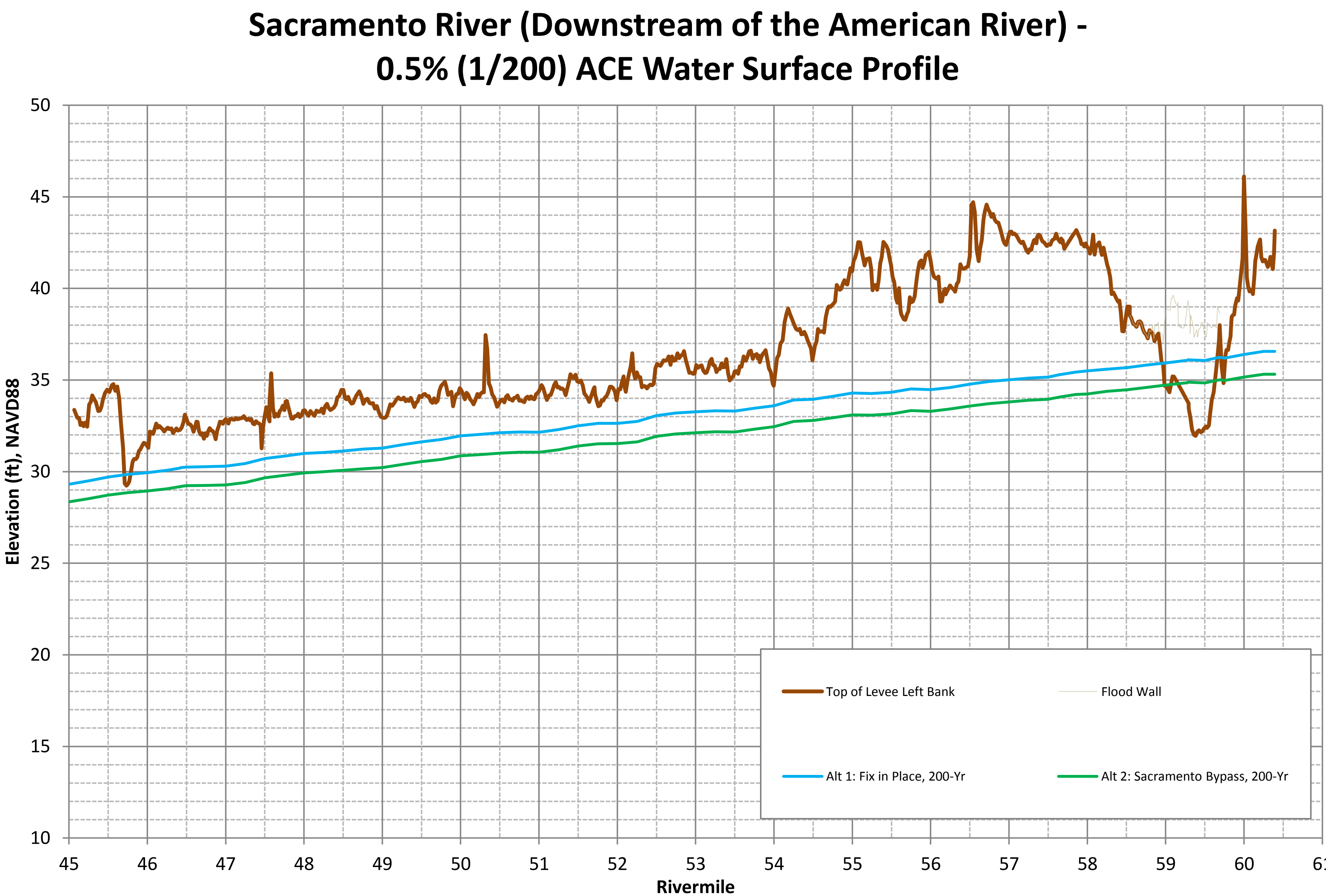
American River Left Bank Levee - 10% (1/10) ACE Water Surface Profile



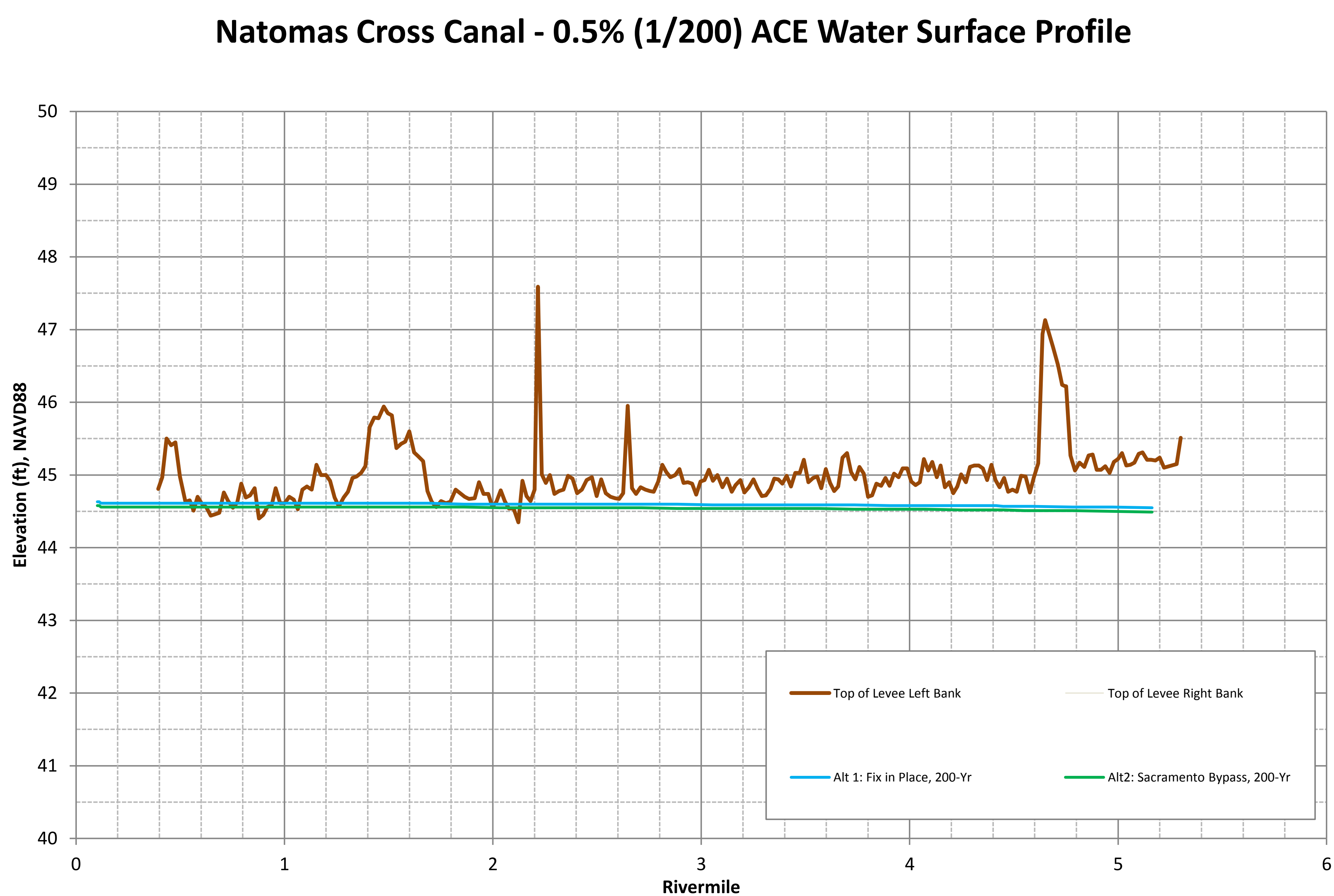
American River Common Features GRR Sacramento, California	American River – Left Bank Levee 10% (1/10) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



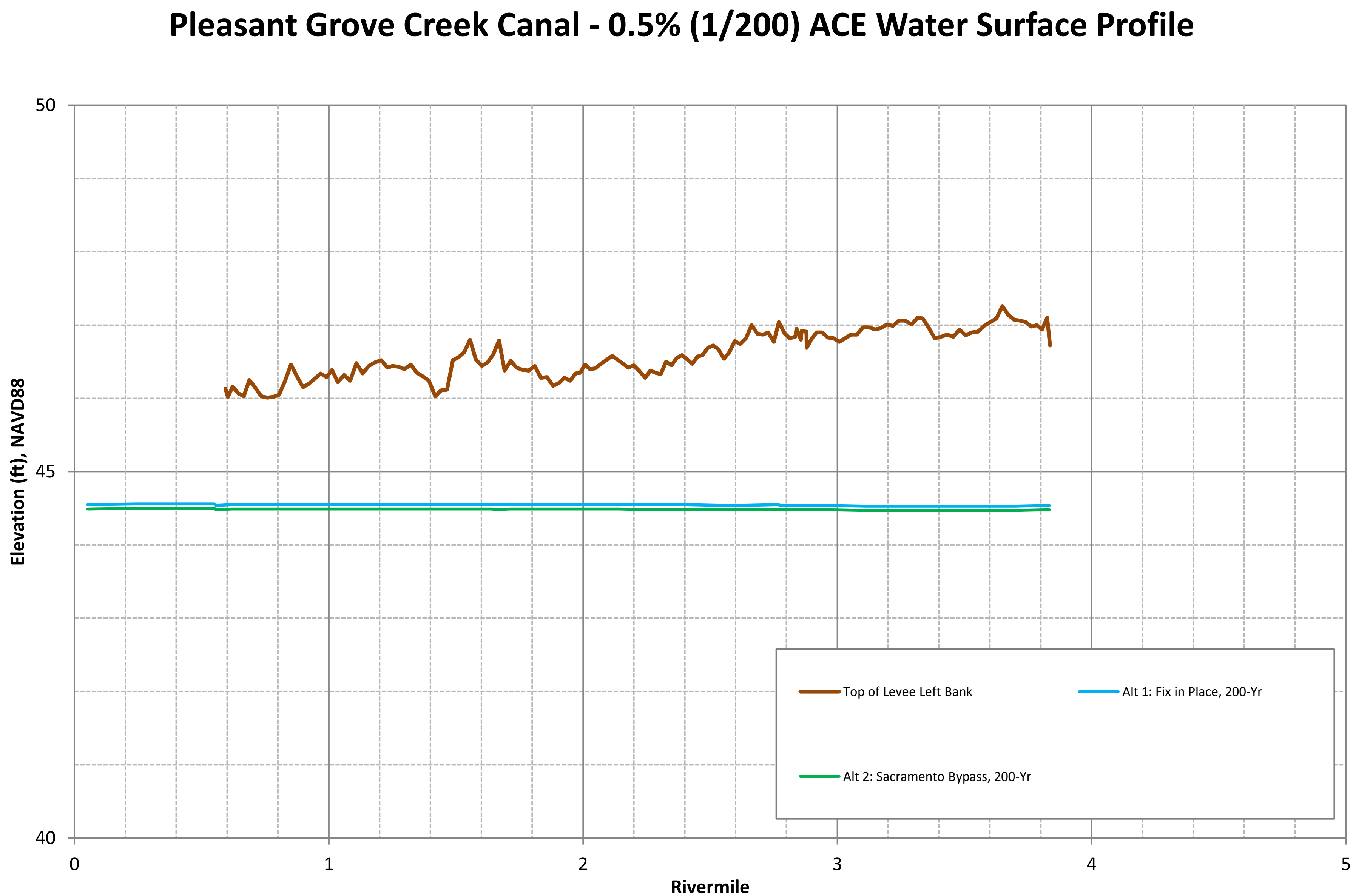
American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

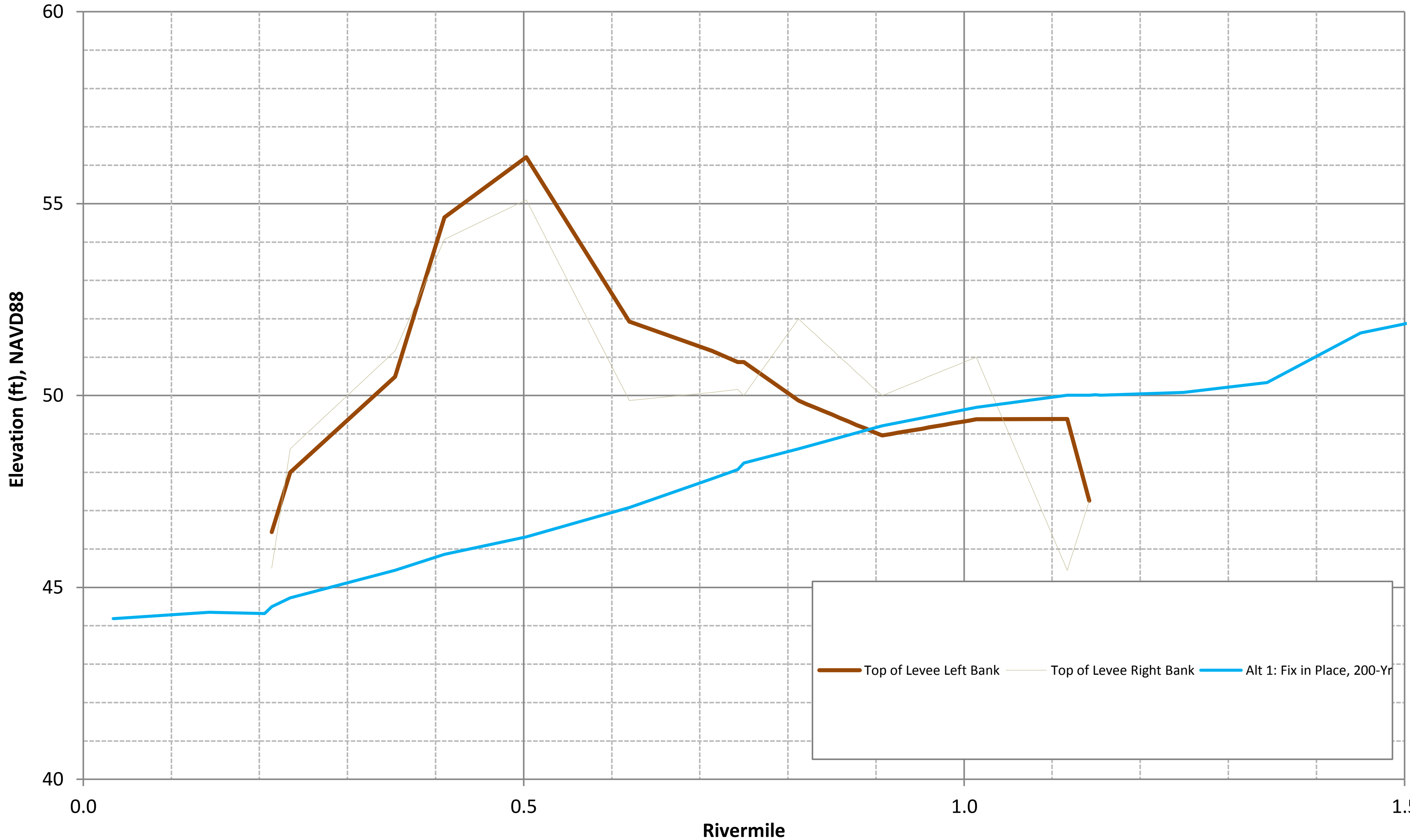


American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

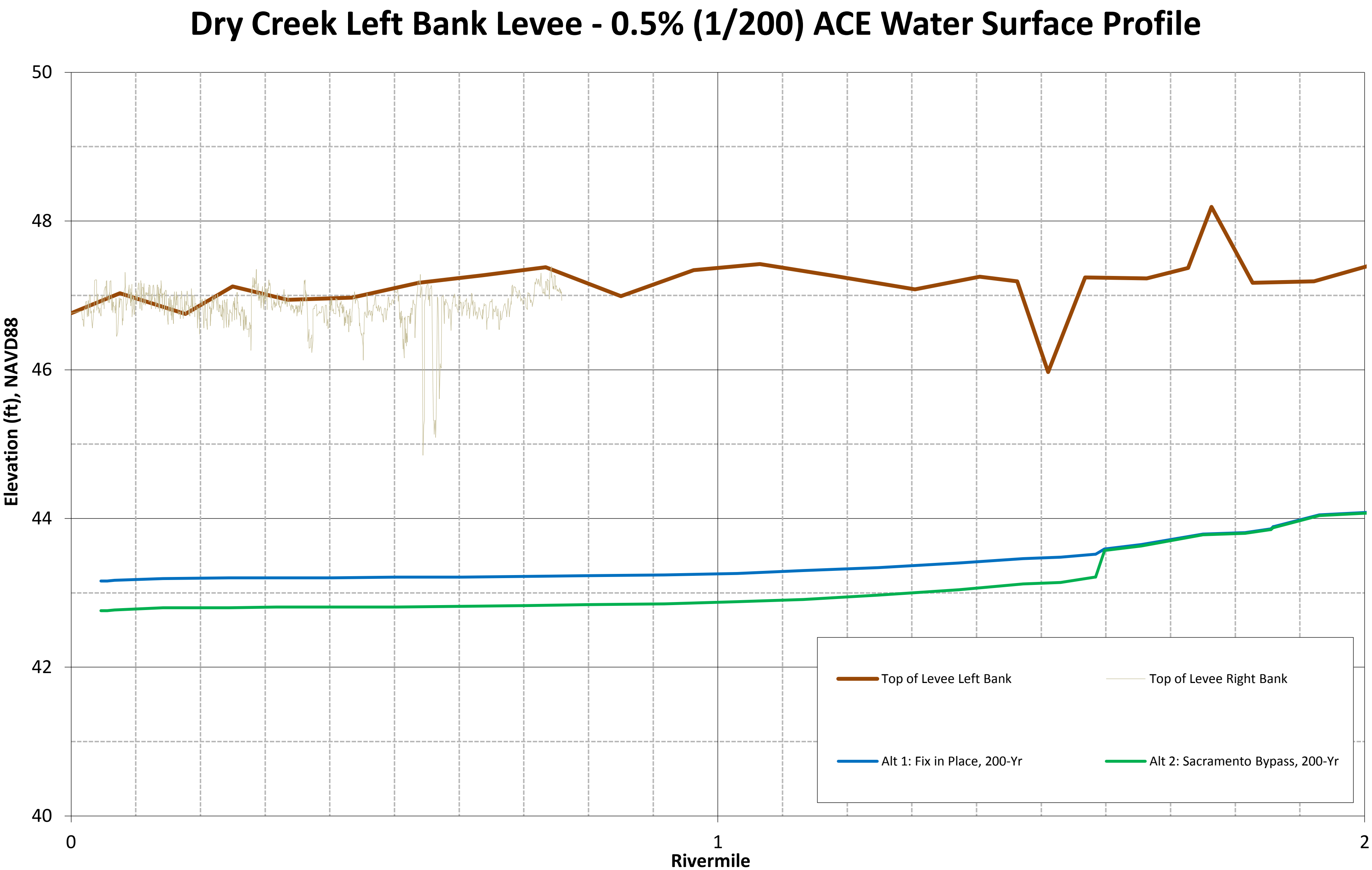


American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Magpie Creek Left Bank Levee - 0.5% (1/200) ACE Water Surface Profile

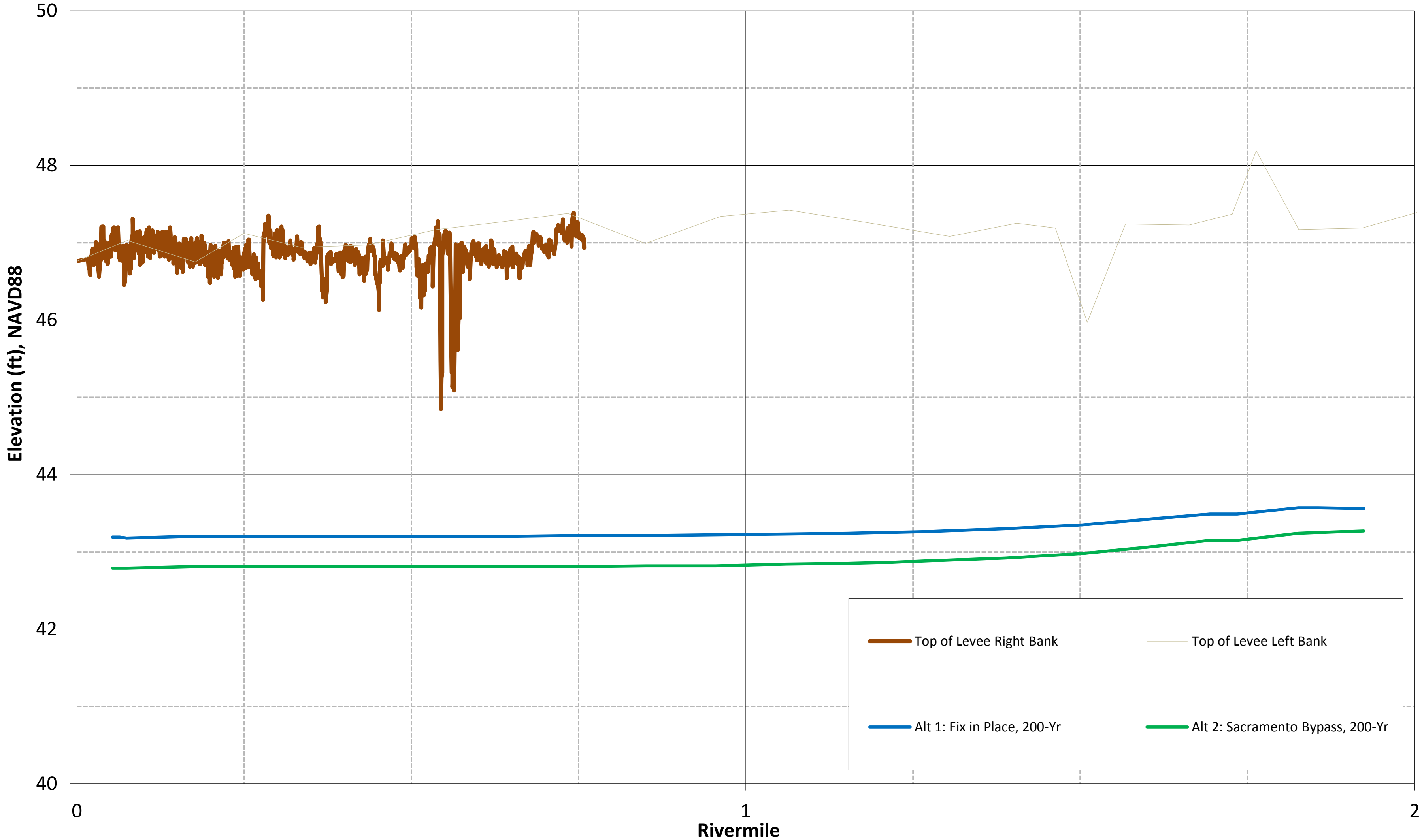


American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



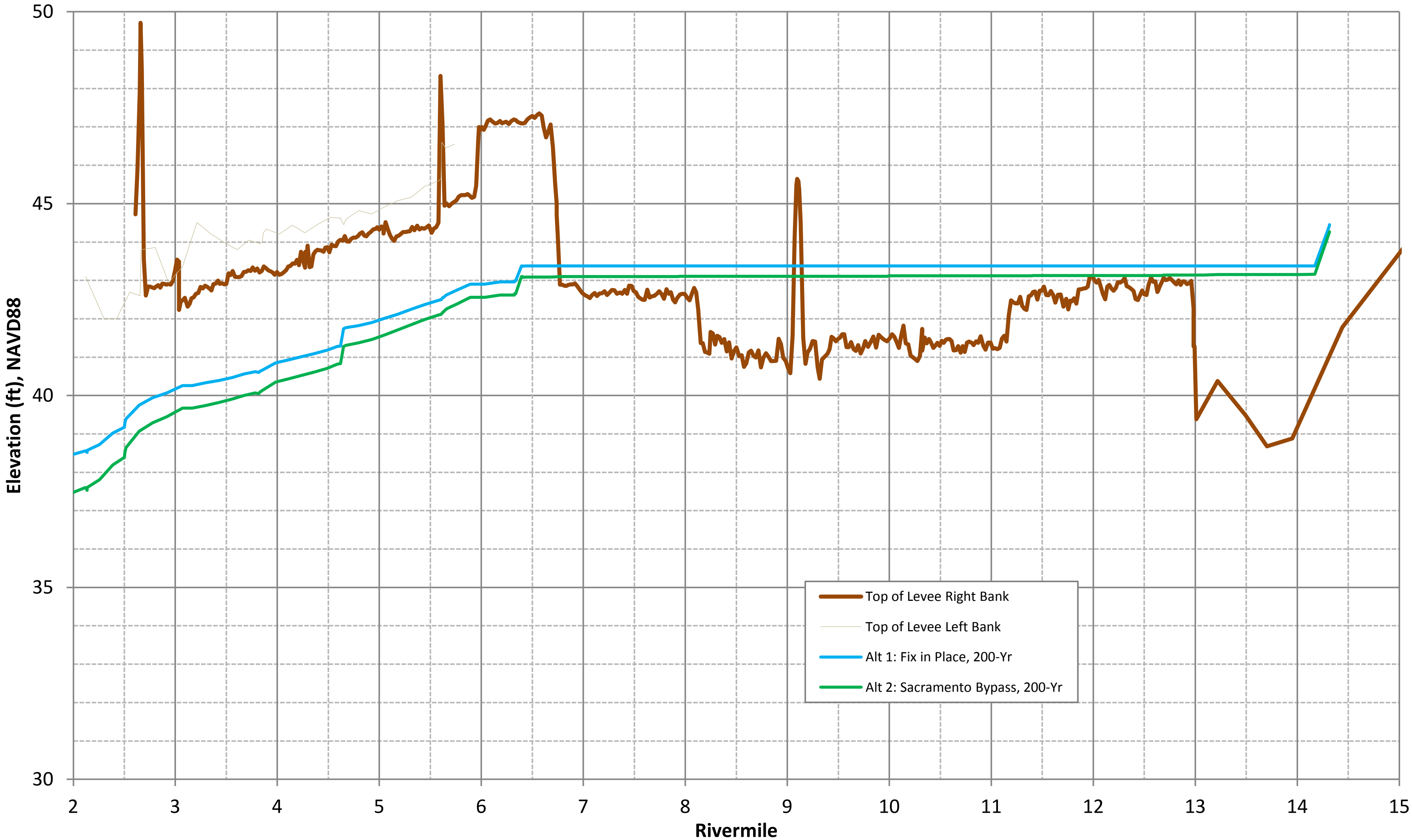
American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Dry Creek Right Bank Levee - 0.5% (1/200) ACE Water Surface Profile



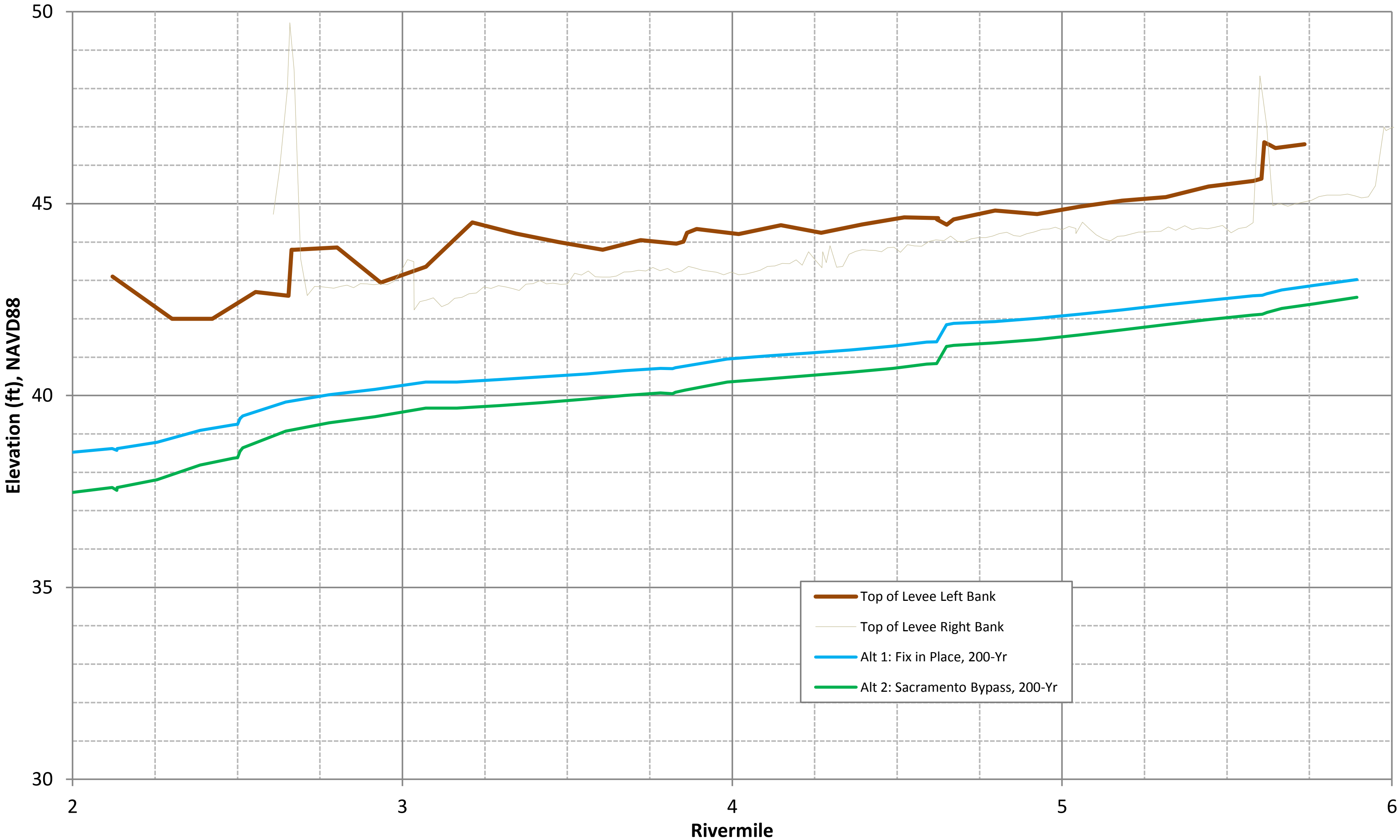
American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

NEMDC Right Levee - 0.5% (1/200) ACE Water Surface Profile



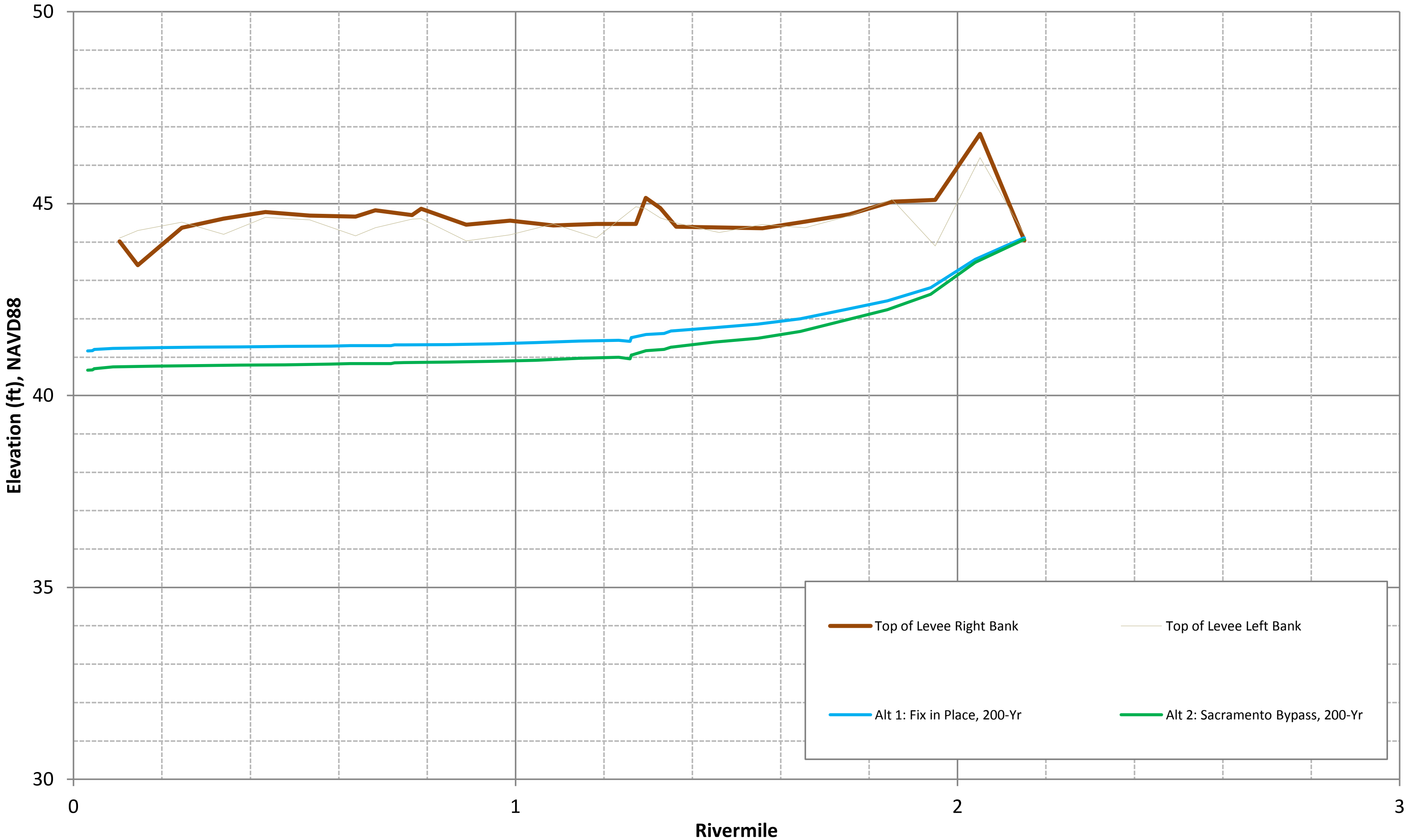
American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

NEMDC Left Levee - 0.5% (1/200) ACE Water Surface Profile



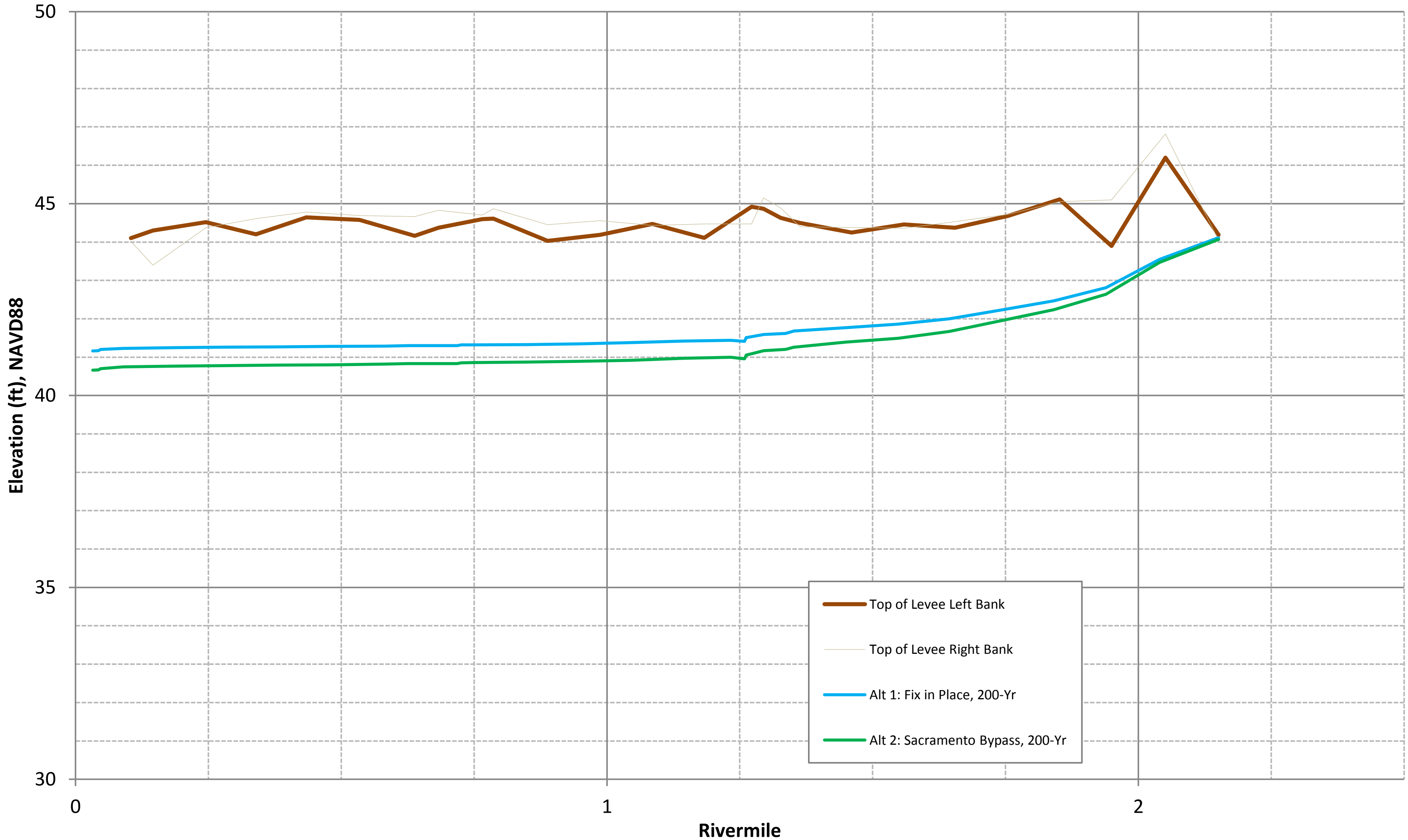
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Arcade Creek Right Bank Levee - 0.5% (1/200) ACE Water Surface Profile

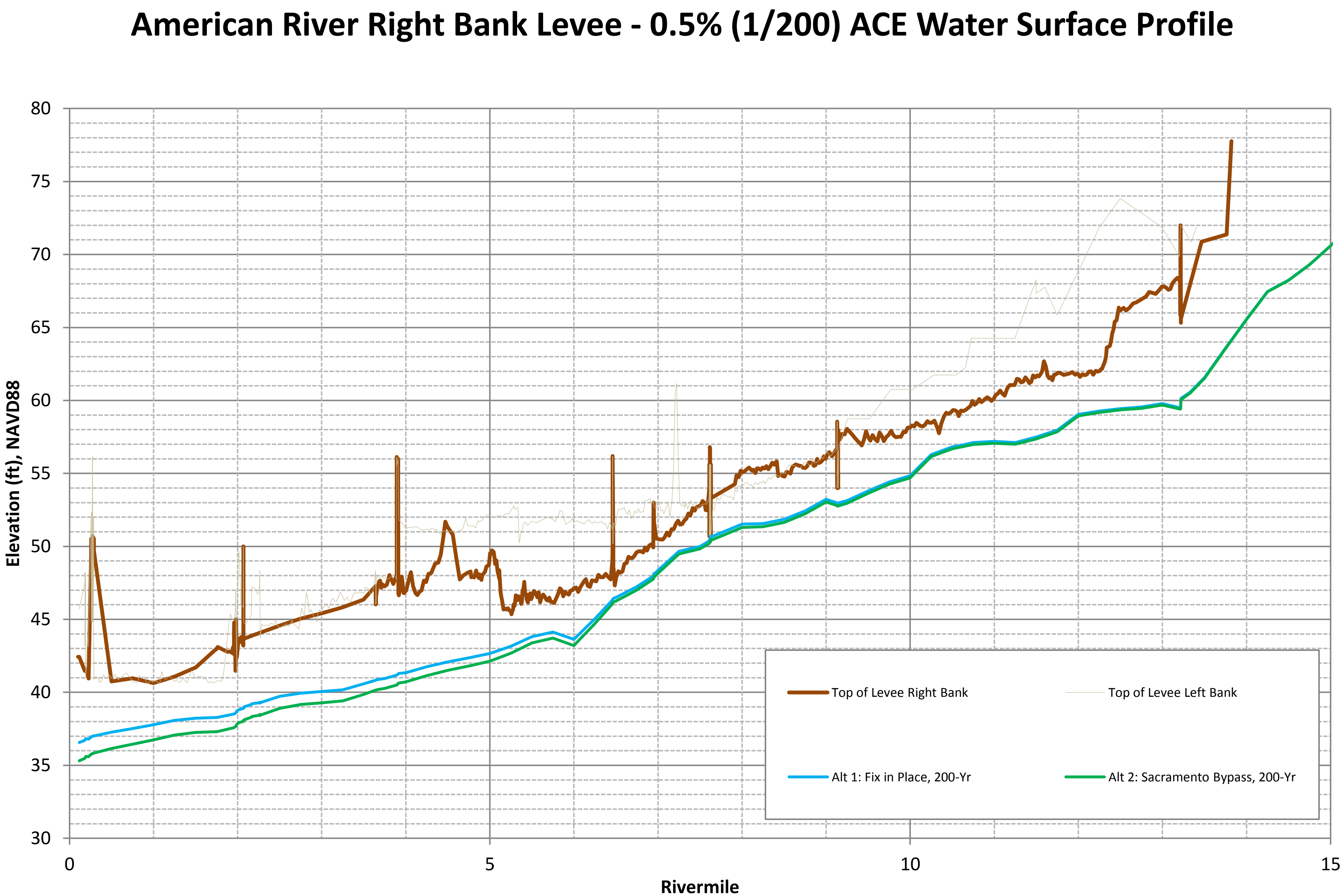


American River Common Features GRR Sacramento, California	Arcade Creek - Right Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Arcade Creek Left Bank Levee - 0.5% (1/200) ACE Water Surface Profile

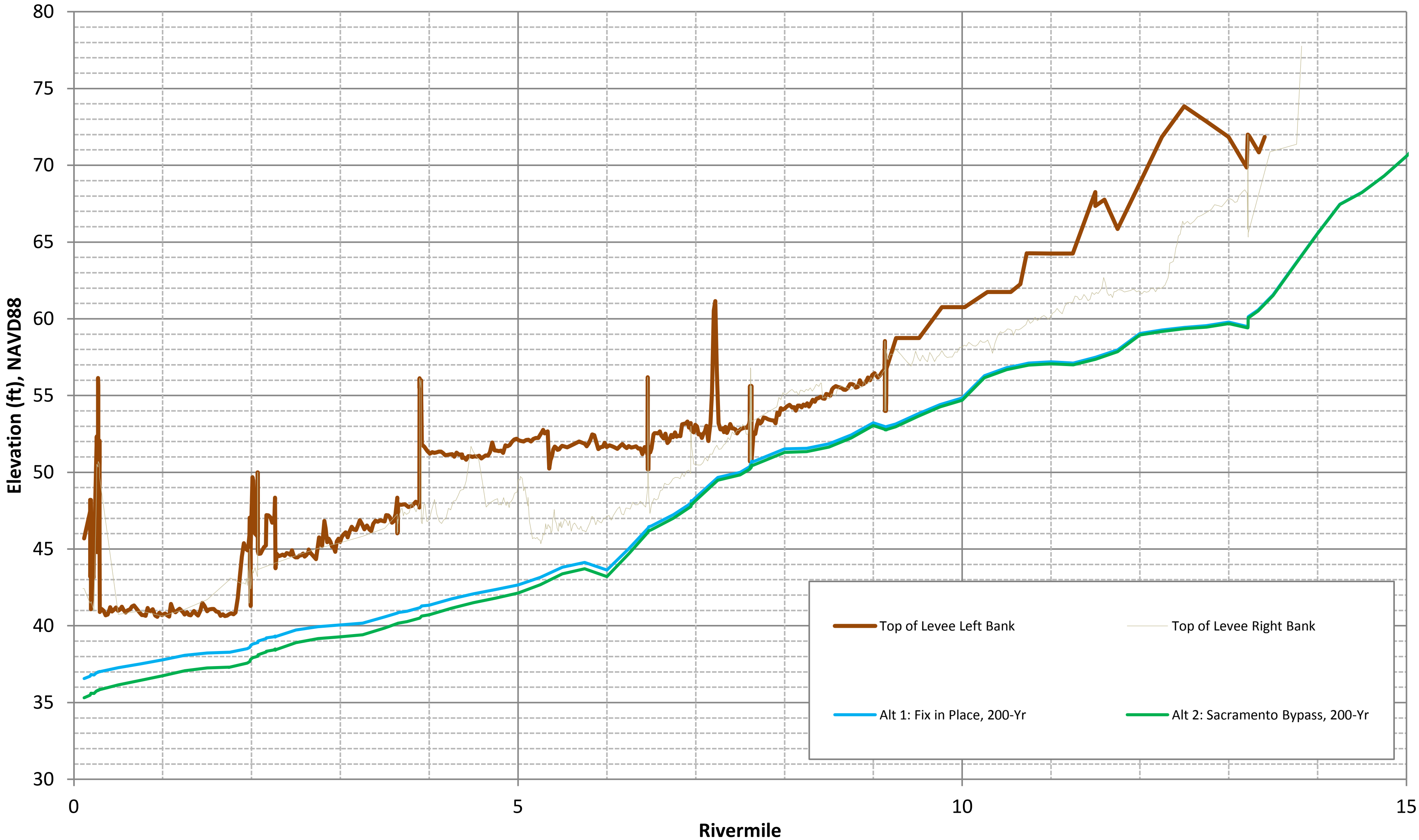


American River Common Features GRR Sacramento, California	Arcade Creek - Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

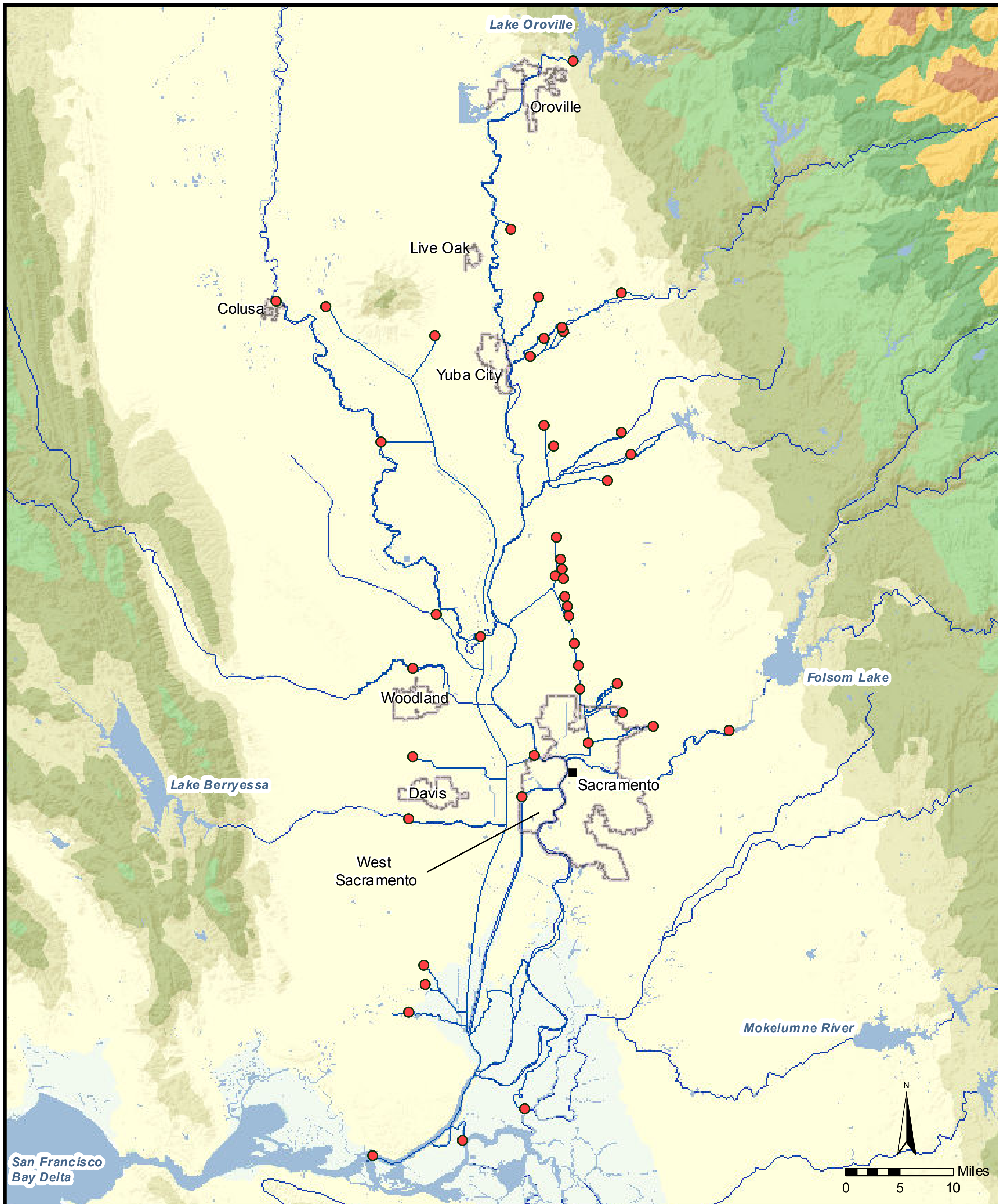


American River Common Features GRR Sacramento, California	American River – Right Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

American River Left Bank Levee - 0.5% (1/200) ACE Water Surface Profile



American River Common Features GRR Sacramento, California	American River – Left Bank Levee 0.5% (1/200) ACE Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



LEGEND

Hydrologic - Hydraulic Handoff Points

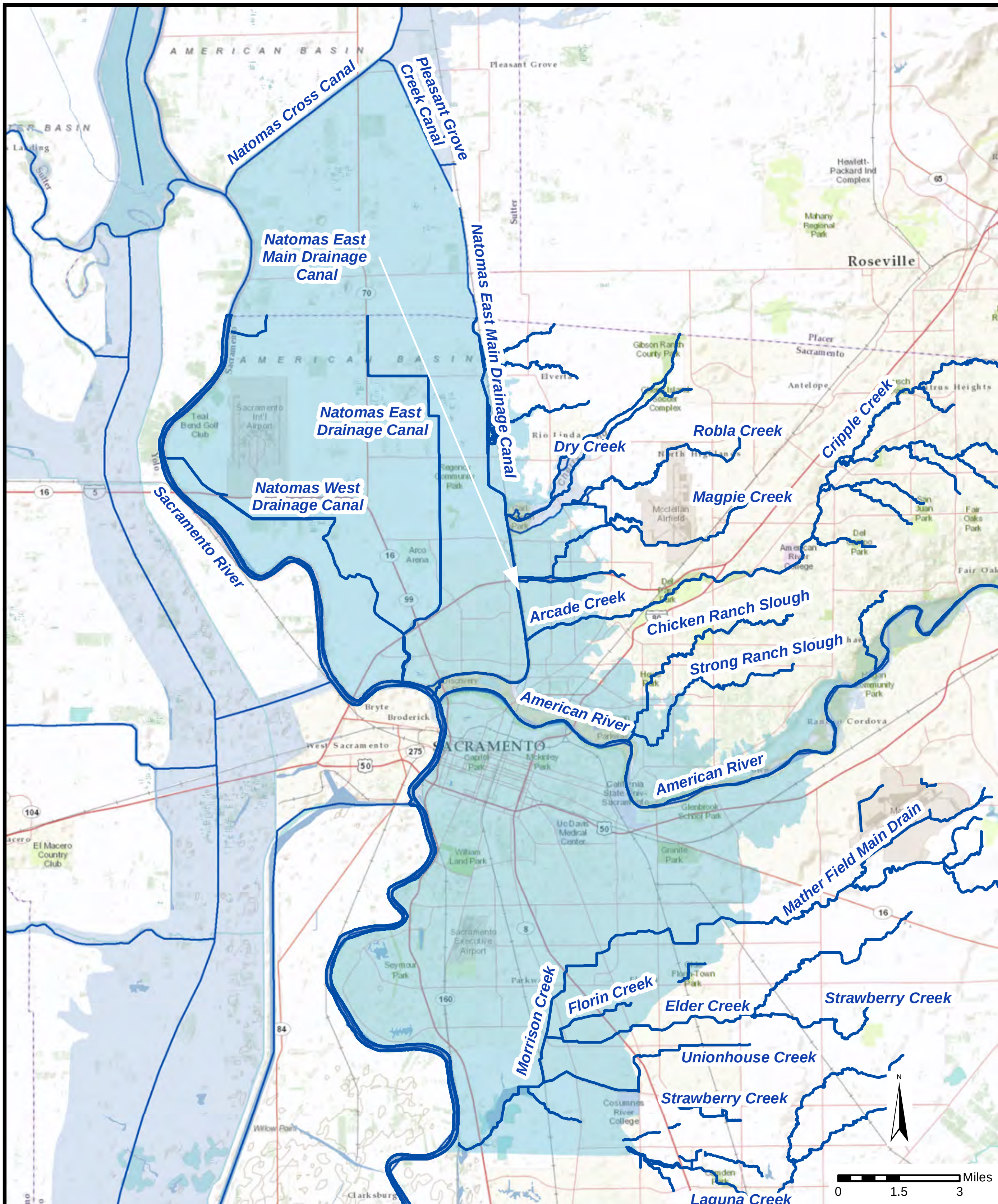
Rivers

Cities

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

BOUNDARY CONDITIONS HYDROLOGIC - HYDRAULIC HANDOFF POINTS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

Streams

Floodways

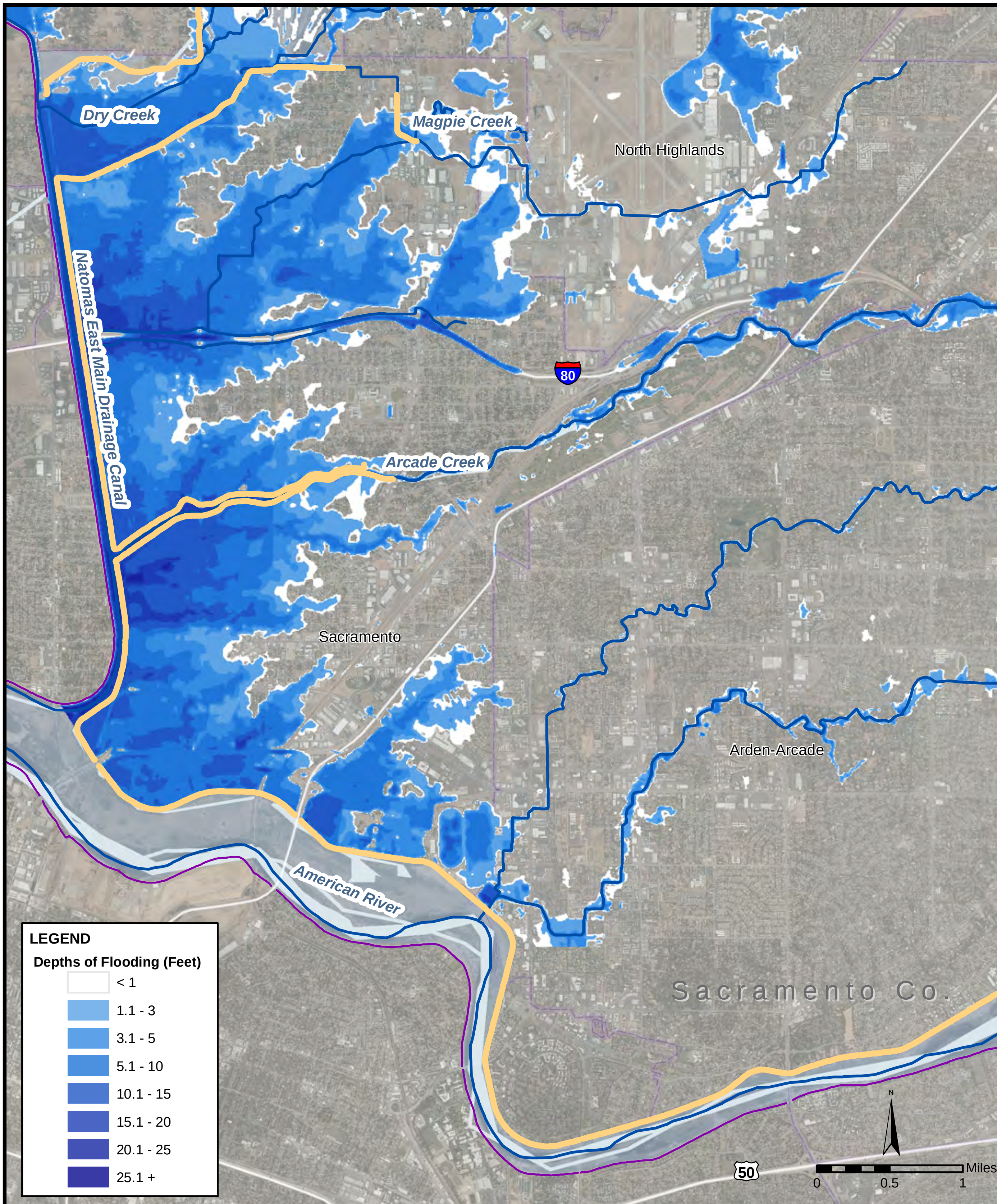
ARCF Study Area

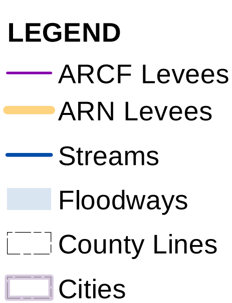
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

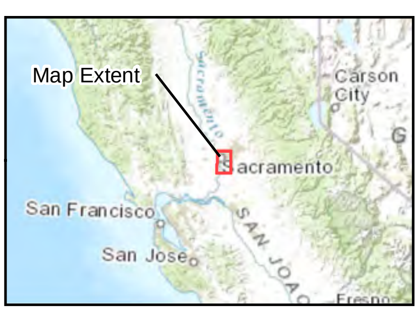
INTERIOR DRAINAGE STUDY AREA MAP

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



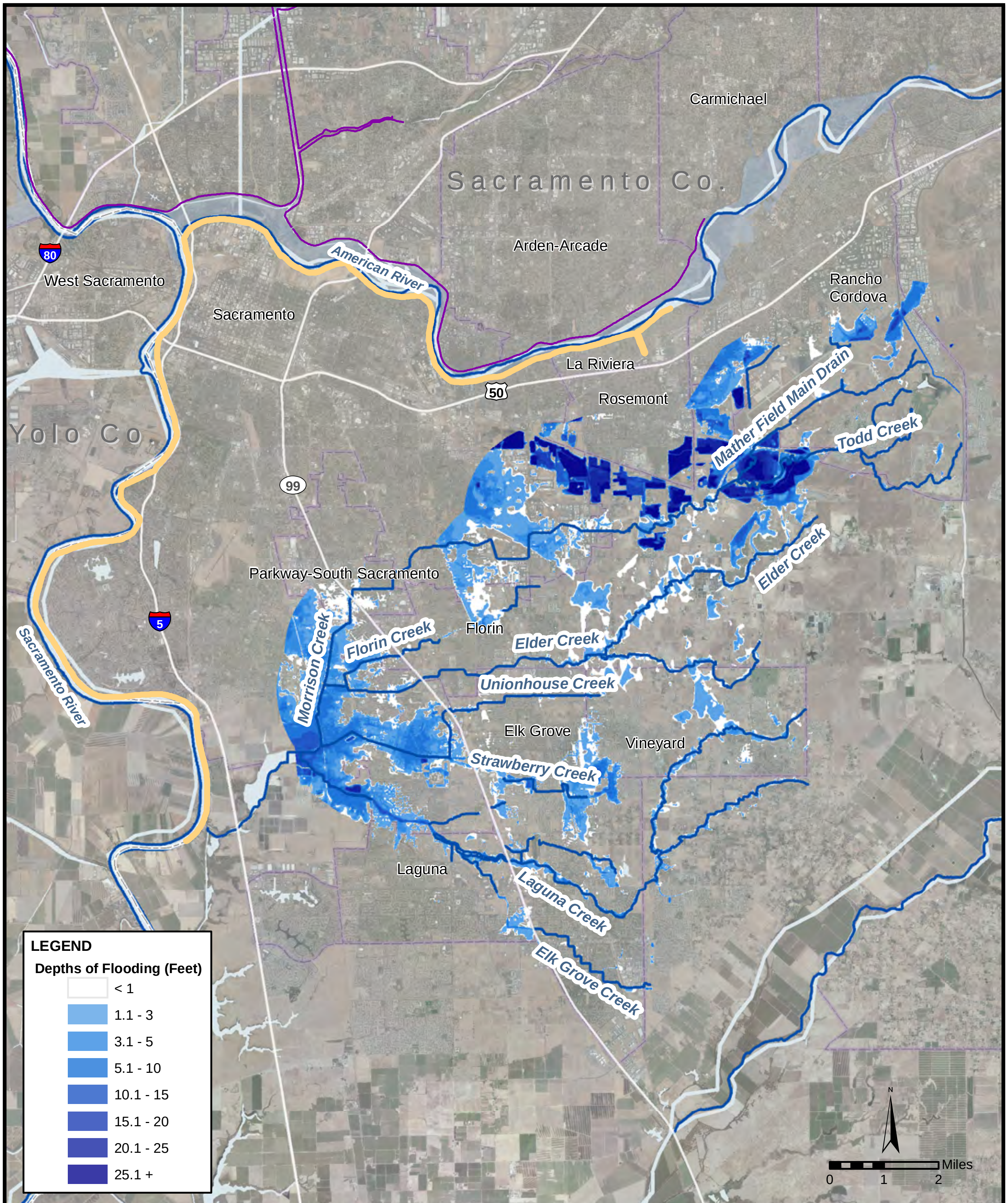




AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

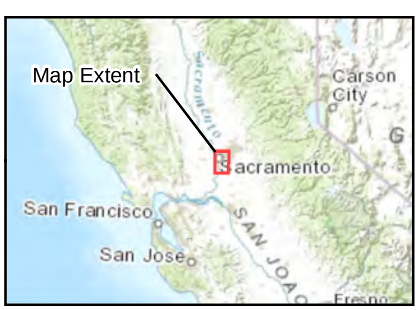
AMERICAN RIVER NORTH 1% ACE (100 YEAR) INTERIOR DRAINAGE FLOODPLAIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

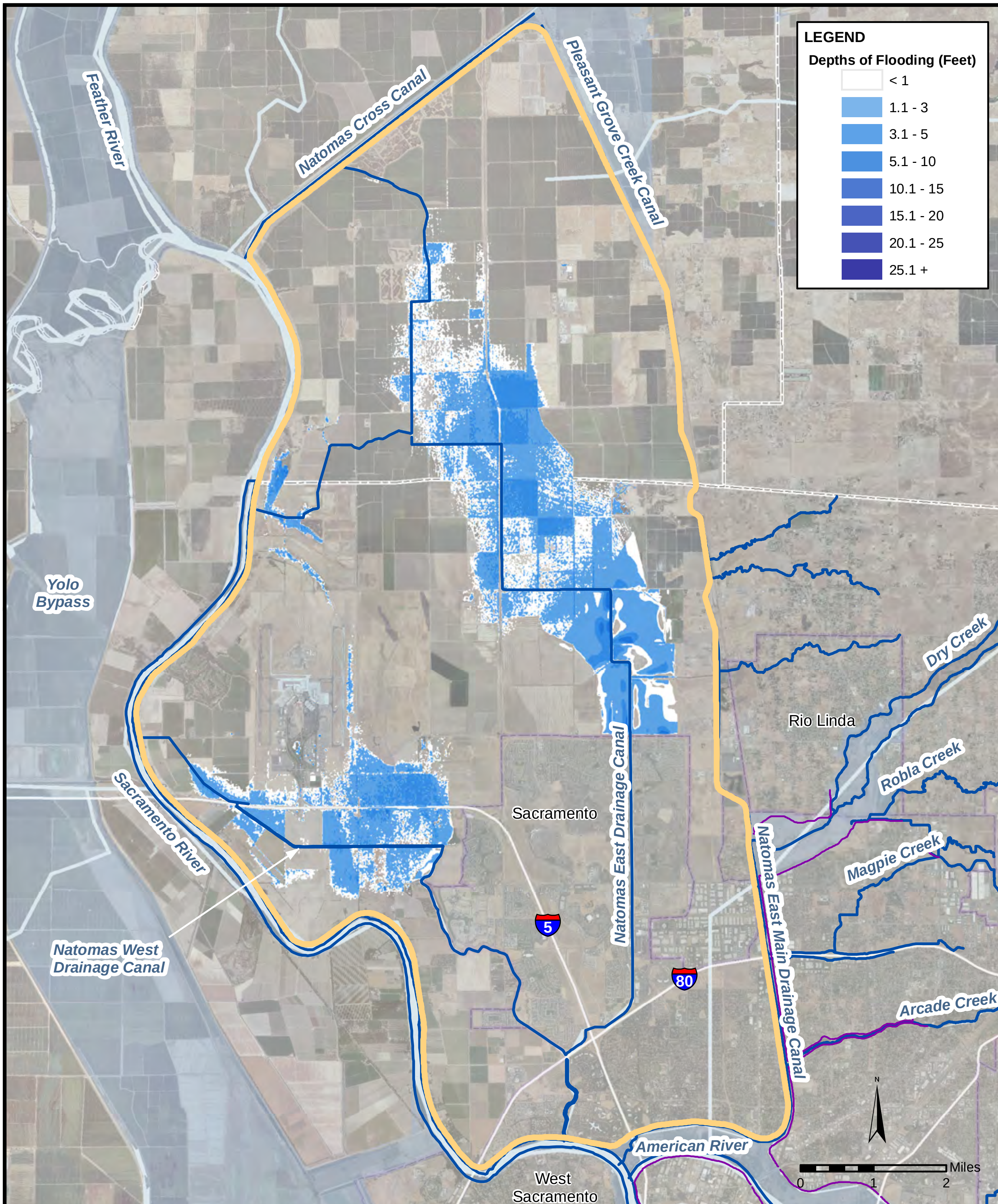
- ARCF Levees
- ARS Levees
- Streams
- Floodways
- County Lines
- Cities



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

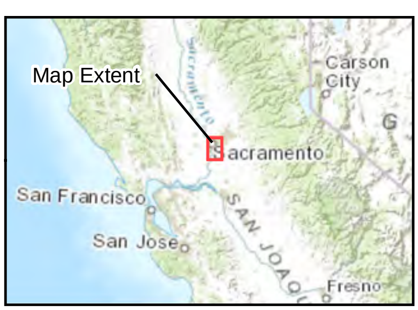
AMERICAN RIVER SOUTH 1% ACE (100 YEAR) INTERIOR DRAINAGE FLOODPLAIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

- ARCF Levees
- Natomas Levees
- Streams
- Floodways
- Cities
- County Lines

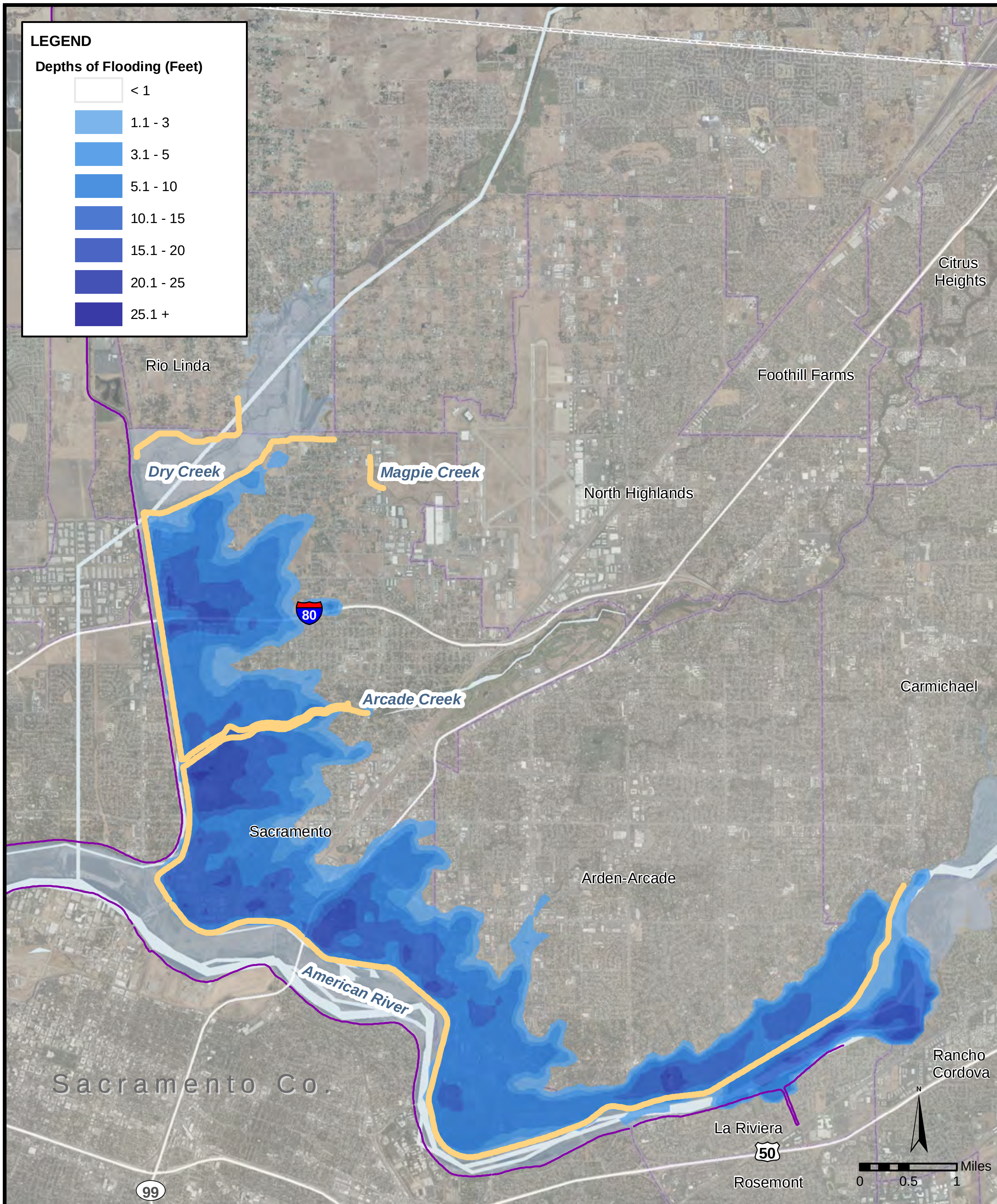


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS BASIN
1% (1/100) ACE
INTERIOR DRAINAGE FLOODPLAIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Jan 2013



LEGEND

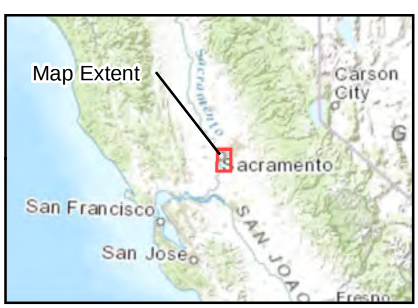
ARN Levees

ARCF Levees

Floodways

County Lines

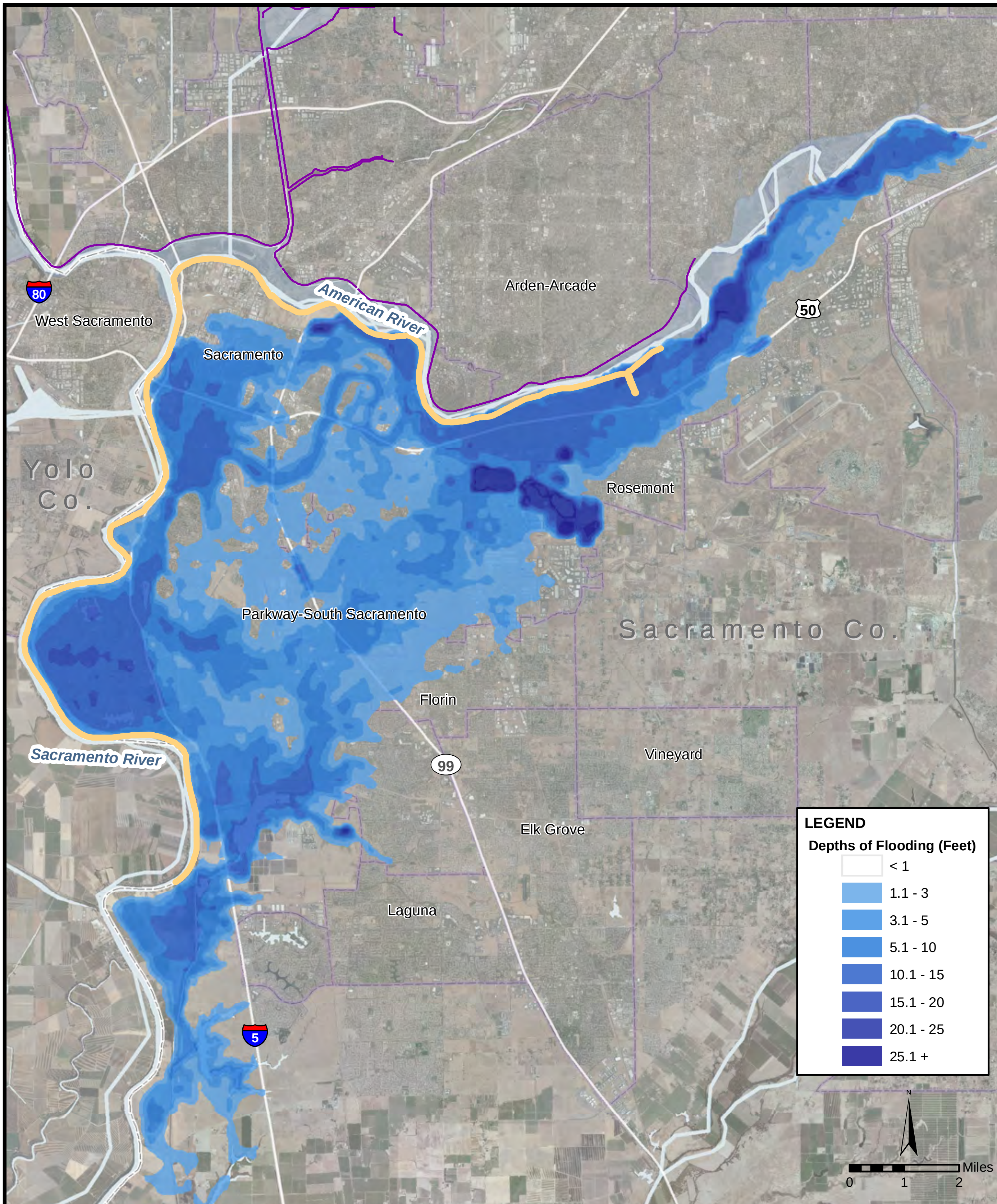
Cities



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

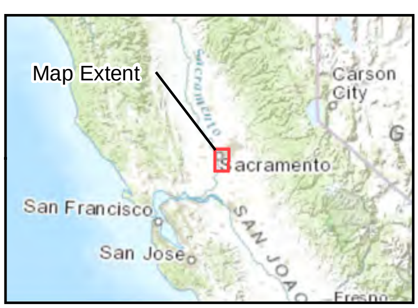
RESIDUAL FLOODING
FROM UPSTREAM CHANNEL OUTFLANKING
INTO THE AMERICAN RIVER BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

- ARCF Levees
- ARS Levees
- County Lines
- Floodways
- Cities

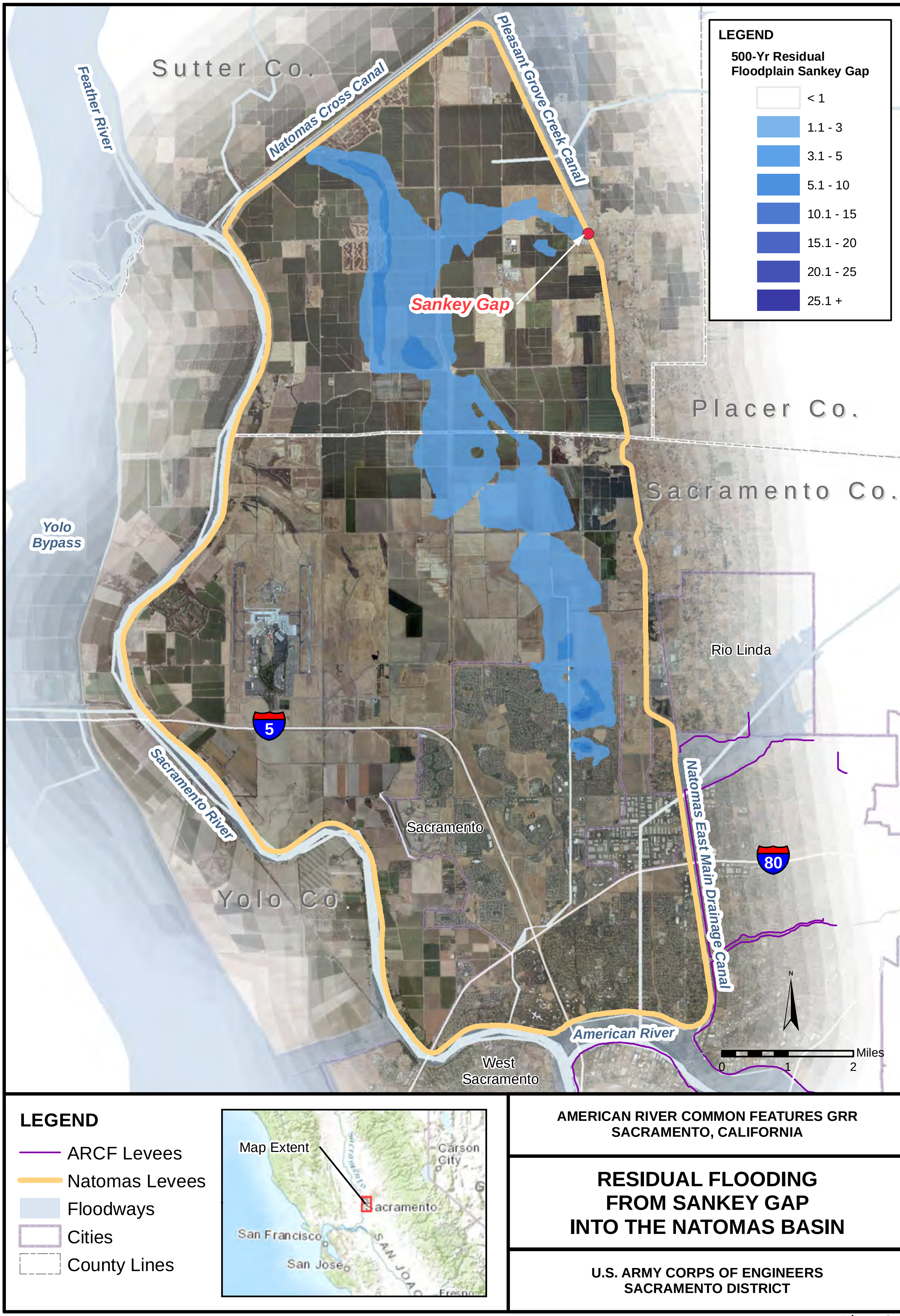


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

RESIDUAL FLOODING FROM CHANNEL OUTFLANKING INTO THE AMERICAN RIVER SOUTH BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

RESIDUAL FLOODING FROM SANKEY GAP INTO THE NATOMAS BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River South (ARS) IP A			
American River RM 7.8			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	24.1	24.1	24.1
2yr = .5	31.9	31.9	31.9
10yr = .1	42.0	42.0	41.8
25yr = .04	48.0	48.0	47.9
50yr = .02	48.1	48.1	47.9
100yr = .01	48.2	48.2	48.0
200yr = .005	53.2	53.2	53.0
500yr = .002	58.1	58.1	58.1
Frequency	Flow		
1yr = .999	1423	1423	1439
2yr = .5	25977	25977	25998
10yr = .1	71654	71654	71655
25yr = .04	114993	114993	114990
50yr = .02	115000	115000	114999
100yr = .01	114999	114999	114999
200yr = .005	159995	159995	159982
500yr = .002	254357	254357	254410

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

**AMERICAN RIVER SOUTH
INDEX POINT A
RISK ANALYSIS INPUTS**

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River South (ARS) IP F			
Sacramento River RM 50.3			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	11.1	11.1	11.1
2yr = .5	20.8	20.8	20.8
10yr = .1	26.4	26.4	26.0
25yr = .04	29.0	29.0	27.9
50yr = .02	29.6	29.6	28.5
100yr = .01	30.3	30.3	29.3
200yr = .005	32.0	32.0	30.9
500yr = .002	33.9	33.9	33.4
Frequency	Flow		
1yr = .999	52823	52823	47842
2yr = .5	94600	94600	87375
10yr = .1	100687	100687	99631
25yr = .04	115395	115395	107204
50yr = .02	118141	118141	110188
100yr = .01	121788	121788	113973
200yr = .005	133200	133200	124750
500yr = .002	152523	152523	144263

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER SOUTH
INDEX POINT F
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River North (ARN) IP A

American River RM 7.83			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	23.3	23.3	22.7
2yr = .5	32.4	32.4	30.5
10yr = .1	40.5	40.5	40.6
25yr = .04	46.2	46.2	46.4
50yr = .02	46.2	46.2	46.5
100yr = .01	46.3	46.3	46.6
200yr = .005	51.2	51.2	51.4
500yr = .002	55.9	55.9	55.7
Frequency	Flow		
1yr = .999	1690	1690	1631
2yr = .5	25969	25969	25996
10yr = .1	71653	71653	71654
25yr = .04	114991	114991	114987
50yr = .02	114999	114999	114999
100yr = .01	115000	115000	114999
200yr = .005	159998	159998	159979
500yr = .002	220684	220684	215253

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH
INDEX POINT A
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River North (ARN) IP E

Arcade Creek RM .95			
	Future Without Project Condition	**Fix In Place**	**Sacramento Bypass Widening**
Frequency	Stage, NAVD88		
1yr = .999	27.0	27.0	26.6
2yr = .5	30.0	30.0	29.4
10yr = .1	33.1	33.1	33.2
25yr = .04	35.4	35.4	34.8
50yr = .02	37.7	37.7	36.1
100yr = .01	39.2	39.2	38.6
200yr = .005	41.4	41.4	40.9
500yr = .002	46.1	46.1	45.2
Frequency	Flow		
1yr = .999	-	-	-
2yr = .5	-	-	-
10yr = .1	-	-	-
25yr = .04	-	-	-
50yr = .02	-	-	-
100yr = .01	-	-	-
200yr = .005	-	-	-
500yr = .002	-	-	-

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH
INDEX POINT E
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

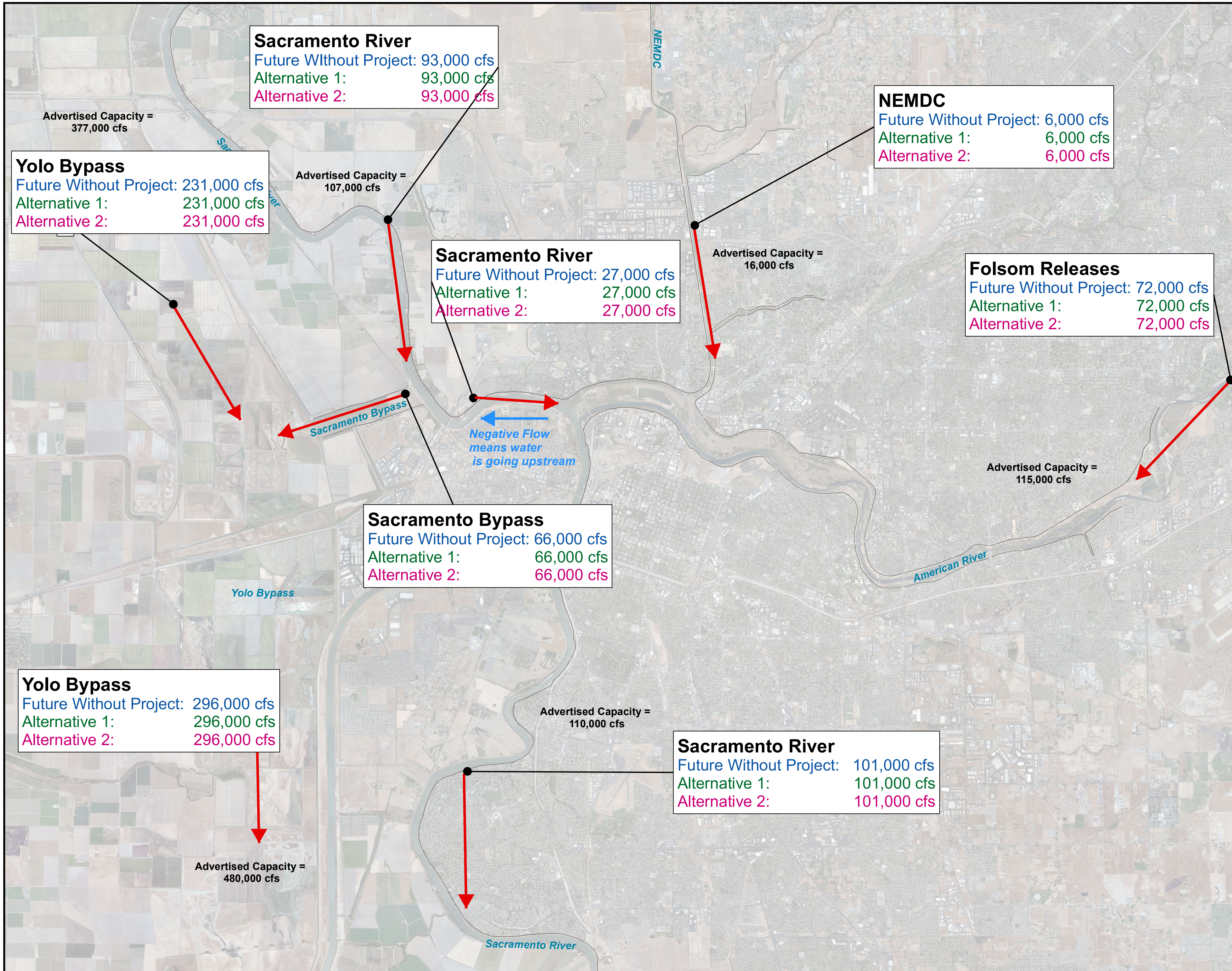
Natomas (NAT) IP D			
Natomas Cross Canal RM 2.71			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	20.6	20.6	20.5
2yr = .5	33.6	33.6	33.5
10yr = .1	39.0	39.0	38.9
25yr = .04	41.5	41.5	41.4
50yr = .02	42.4	42.4	42.3
100yr = .01	43.5	43.5	43.4
200yr = .005	44.6	44.6	44.6
500yr = .002	45.5	45.5	45.5
Frequency	Flow		
1yr = .999	-	-	-
2yr = .5	-	-	-
10yr = .1	-	-	-
25yr = .04	-	-	-
50yr = .02	-	-	-
100yr = .01	-	-	-
200yr = .005	-	-	-
500yr = .002	-	-	-

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS
INDEX POINT D
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

- Levee Reaches (ARCF)
- Flow Direction
- Backflow

Reach
Future Without Project Condition Flows
Alternative 1 Flows
Alternative 2 Flows

N

0 0.5 1 2 Miles

1:100,000

US Army Corps of Engineers
Sacramento District

Maximum 10% (1/10) ACE Future Without Project Conditions & With Project Flows

AMERICAN RIVER
COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.

Date: 9/8/2015
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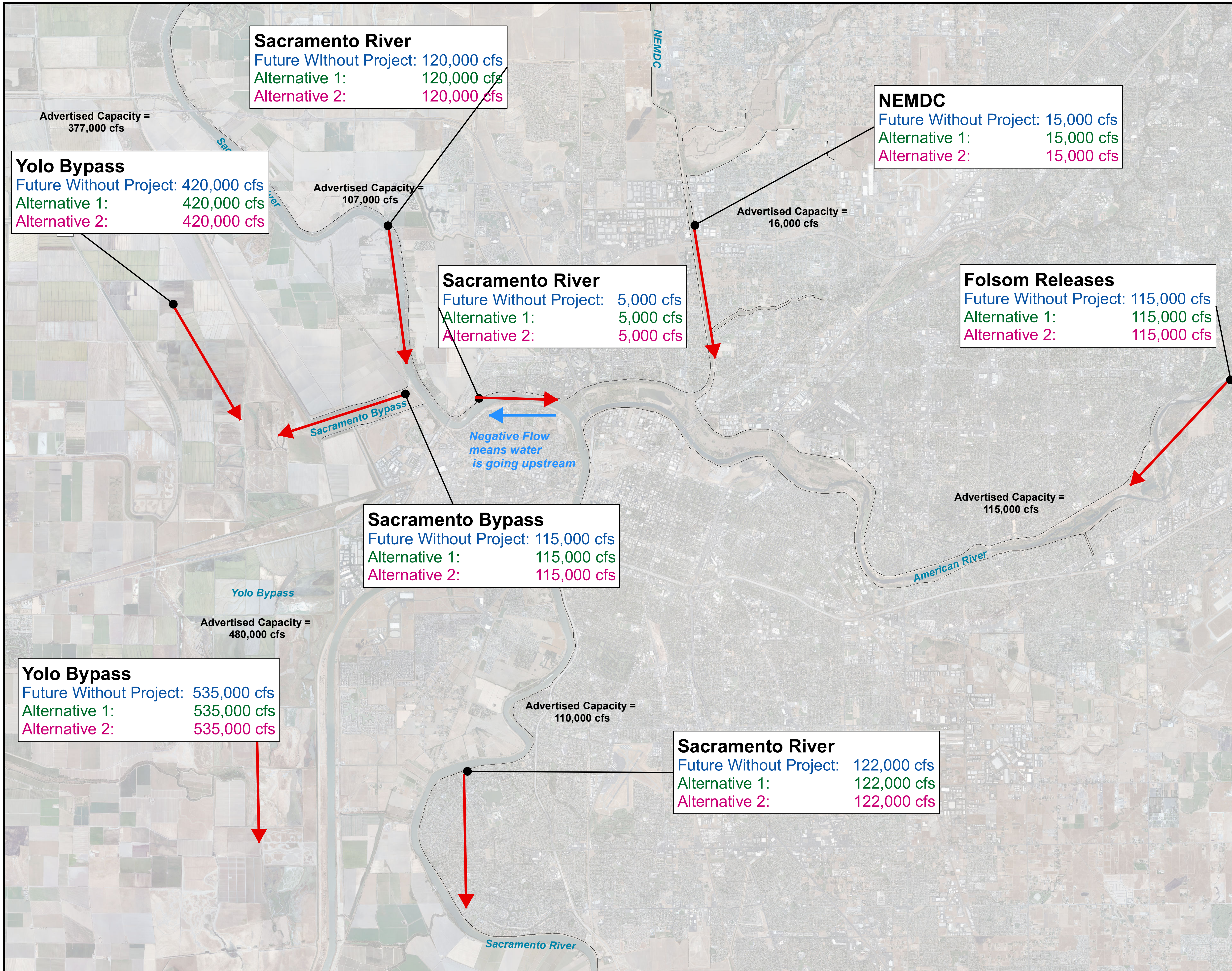


LEGEND

- Levee Reaches (ARCF)
- Flow Direction
- Backflow

Reach
Future Without Project Condition Flows
Alternative 1 Flows
Alternative 2 Flows

N

0 0.5 1 2 Miles

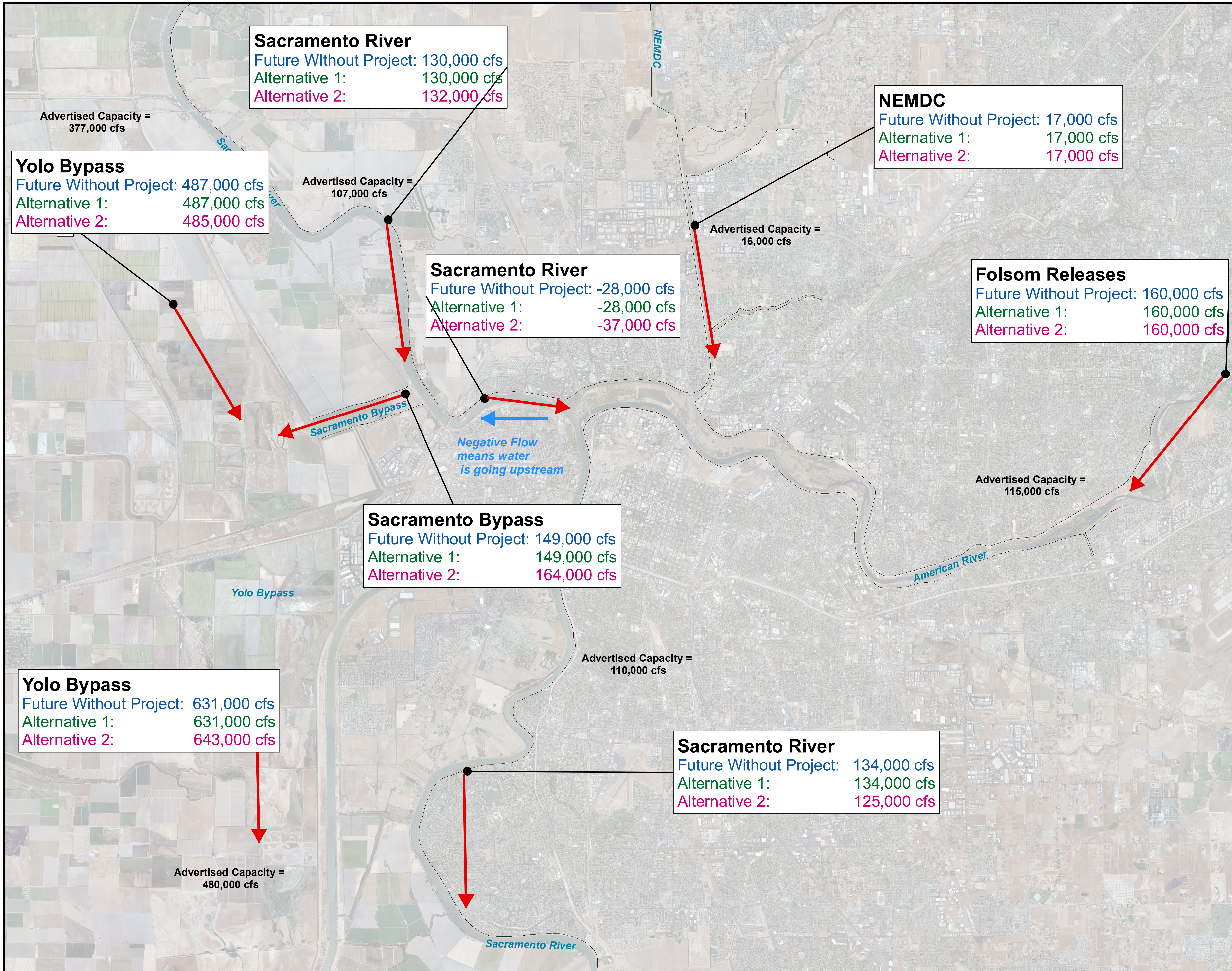
1:100,000

US Army Corps of Engineers
Sacramento District

Maximum 1% (1/100) ACE Future Without Project Conditions & With Project Flows

AMERICAN RIVER COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.



LEGEND

- Levee Reaches (ARCF)
- Flow Direction
- Backflow

Reach
Future Without Project Condition Flows
Alternative 1 Flows
Alternative 2 Flows

N

0 0.5 1 2 Miles

1:100,000

US Army Corps of Engineers
Sacramento District

Maximum 0.5% (1/200) ACE Future Without Project Conditions & With Project Flows

AMERICAN RIVER COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.

Date: 9/8/2015
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Sept 2015